A man from Gorkha

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Bachlor in Agricultural
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From "Gorkha"
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Subject:- Hydrology and Agricultural meteorology.

Chapter 1 :- Introduction to Hydrology and Hydrologic cycle.

Defination :-

Hydrology means the Science of Water. It is the Science that deals with the occurrence, circulation and distribution of water of the earth and earth's atmosphere.

Hydrology is basically an applied science, To further emphasise the degree of aplicability, the subject is sometimes classified as the;

1. Scientific hydrology :-
The Study which is concerned chiefly with academic aspects.
2. Engineering or applied hydrology :-
A study concerned with engineering applications

In general sense engineering hydrology deals with

1. estimation of water resources,
2. The study of processes such as precipitation, runoff, evapotranspiration and their interaction.
3. The study of problems such as floods and droughts, and strategies to combat them.

Scope of Hydrological study and its application in agricultural engineering :-

The scope of hydrological study and its application in agricultural Engineering are discussed below.

1. Water resource project:-

Hydrology finds it gretest application in the design and application of water resources project. the hydrological study of a project should necessarily precede structural and other detail studies. It involves the collection of relevent data and analysis of data by applying the principle and theories of hydrology to seek solution of practical problems.

2. Drinking water supply :-

There is a great scope of hydrology in drinking water supply. drinking water should be distributed through out the place through water pump, water pipes etc. from the rivers or reservoirs.

3. irrigation and drainage engineering :-
- In irrigation project and hydraulics structure, there finds a great scope, while designing irrigation canal & projects.

4. Water power :-
- Nepal is in developing stage, so there's comes many hydropower where it has great scope.

5. Navigation :-
- Navigation is the field of study that focuses on the process of monitoring and controlling the movement of craft or vehicle from one place to another.

6. Recreational uses.
7. Bridge, dam, reservoir etc.

Application of hydrology in agricultural engineering field :-

1. Designing irrigation schemes and managing agricultural productivity.
2. Determing the water balance of a region.
3. Determing the agricultural water balance.
4. Designing dam's for water supply or hydroelectric power generation.
5. Providing drinking water.
6. Designing sewers and urban drainage system.
7. Assessing the impacts of natural and anthropogenic environment change on water resources.

8: mitigating and predicting flood, Landslide and drought risk.

Hydrological cycle and it's components :-

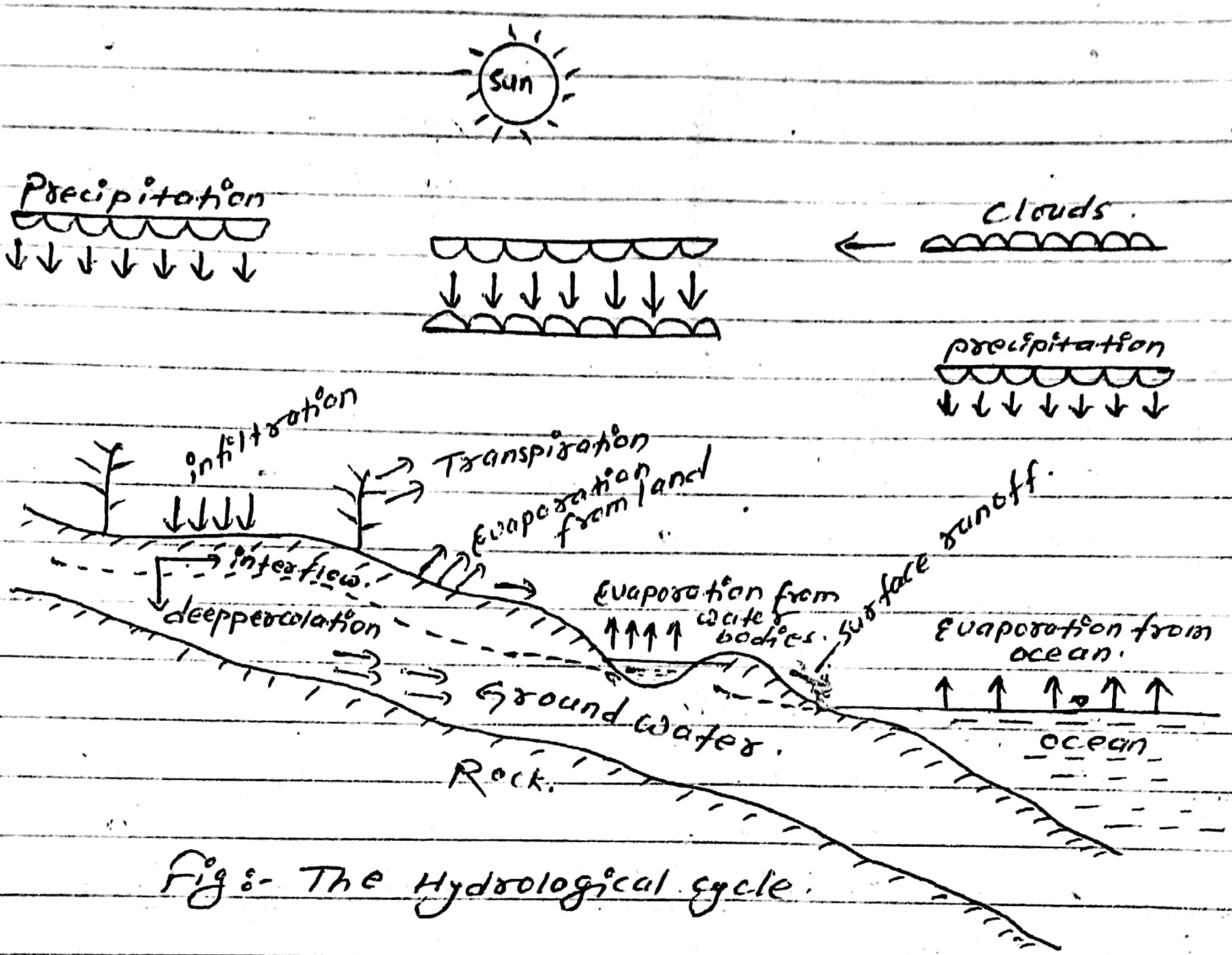


Fig :- The Hydrological cycle.

Water occurs on the Earth in all its three states, viz, Liquid, solid and gaseous, and in various degree of motion. Evaporation of water from water bodies such as oceans and lakes, formation and movement of clouds, rain and snowfall, streamflow and groundwater movement are some examples of the dynamic aspects of water. The various aspects of water related to the earth can be explained in terms of a cycle known as the hydrologic cycle.

The three important phase of hydrological cycle are;

1. Evaporation and Evapotranspiration
2. precipitation.
3. runoff.

Figures above represents the schematic representation of hydrological cycle.

Components of Hydrological cycle are;

1. Evaporation
2. precipitation
3. Transpiration
4. Interception/Infiltration
5. Run off.
6. Groundwater.

A convenient starting point to describe the cycle is in the oceans. Water in the ocean evaporate due to heat energy provided by solar radiation. the water vapour moves upward and form clounds. While much of the cloud condense and fall back to the ocean as rain, a part of clouds is driven to the land areas by wind. There they condense and precipitate onto the land mass as rain, snow, hail, sleet etc. a part of the precipitation may evaporate back to the atmosphere even while falling. another part may be intercepted by vegetation, structure and other such-surface modification from which it may be either evaporated back to the atmosphere or move down to the ground surface.

A portion of water that reaches the ground enters the earth's surface through infiltration,

enhance the moisture content of the soil and reach the groundwater body. vegetation sends a portion of water from under the ground surface back to the atmosphere through the process of transpiration. The precipitation reaching the ground surface after meeting the needs of infiltration and evaporation moves down the natural slope over the surface and through the network of gullies, stream and rivers to reach the ocean. The portion of the precipitation which by a variety of path above and below the surface of the earth reaches the stream channel is called runoff. once, it enters a stream channel, runoff becomes stream flow.

[Note :- The main component of hydrological cycle can be broadly classified as transportation (flow) components and storage components;

1. Transportation Components
   - precipitation
   - Evaporation
   - Transpiration
   - Infiltration
   - Run off

2. Storage components
   - storage on land surface (Depression storage, ponds, Lakes, Reservoir etc).
   - Soil moisture storage.
   - Groundwater storage.]

Water balance equation/water budget Equation:-

- The quantities of water going through various individual path of the hydrological cycle in a given system can be described by the continuity principle known as water budget equation or hydrologic equation.

Catchment area:- The area of land draining into a stream or a water course at a given location is known as catchment area. It is also called as drainage area or drainage basin. In USA, it is known as Watershed.

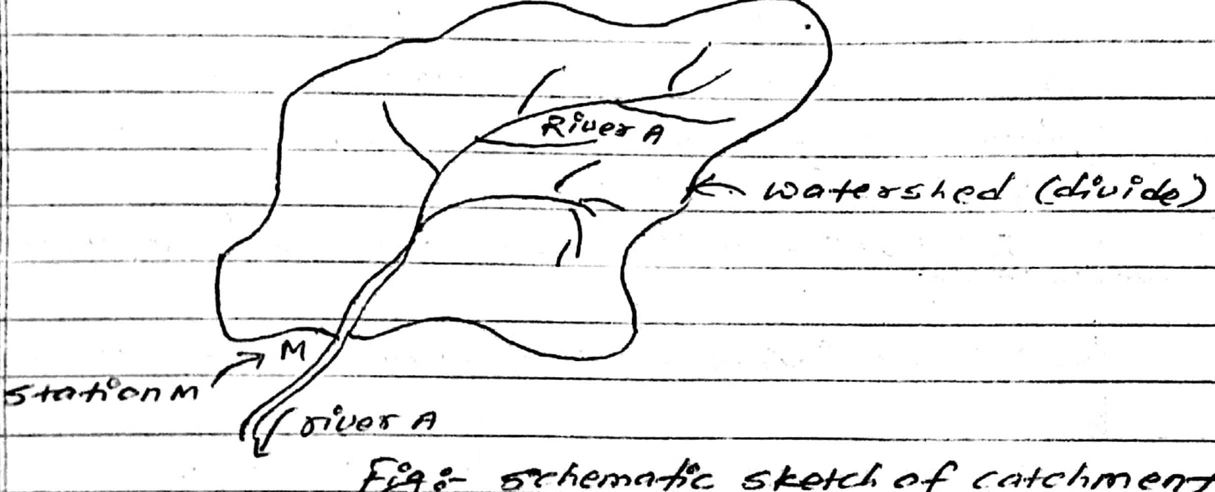


Fig:- schematic sketch of catchment of River A at station M.

For a given problem area, say a catchment, in an interval of time Δt, the continuity Equation for water in it's various phase is written as;

Mass inflow - mass outflow = Change in mass storage

An Expression for the water budget of a catchment for a interval Δt is written as;

$$P - R - G - E - T = \Delta S.$$

Where; P = precipitation
R = surface runoff
G = net groundwater flow out of the catchment.
E = Evaporation
T = transpiration
ΔS = change in storage.

The storage S consists of three components

$$S = S_s + S_{sm} + S_g$$

Where; S_s = surface water storage
S_{sm} = Water in storage as soil/moisture and
S_g = Water in storage as groundwater.

__or:__

If 'S_1' be the initial storage and 'S_2' be the final storage then, water balane equation can be obtained as;

$$S_1 + ppt^n - \text{infiltration} - \text{Evaporation/transpiration} - RO = S_2$$

$$\text{Total inflow} - \text{Total outflow} = S_2 - S_1 = \Delta S.$$

Importance of Hydrological Studies :-

The important of hydrology is seen in;

1. Design of Hydraulics structure.
2. municipal and Industrial water supply
3. Irrigation
4. Hydroelectric power generation
5. Flood control in rivers
6. Navigation.
7. pollution control.

1. Design of Hydraulic structures :-

Hydraulic structures such as bridge, cause ways, dams, spillways etc. need accurate hydrological prediction for their proper functioning. Due to storm, the flow below a bridge has to be properly predicted. Improper prediction may cause failure of the structure. Similarly the spillway should also be designed properly otherwise flooding water may overtop the dam.

2. Municipal and industrial water supply :-

For a supply of water, water should be drawn from rivers, streams, ground water proper estimation of water resources in place will help planning and implementation of facilities for municipal and industrial water supply.

3. Irrigation :-

Dams are constructed to store water, for estimating maximum storage capacity, seepage evaporation and other losses should be properly estimated. To make irrigation project successful, proper understanding of hydrology of a river and basin is important.

4. Hydroelectric power generation :-

Large variation in the stream flow affect the functioning of turbines ~~and~~ in the electric plant. Hence estimation of river flow and flood occurances is important.

Numerical portion

K.S. 1.1. Two and half centimeters of rain per day over an area of 2000 km² is equivalent to average rate of input of how many cubic meter per second of water to that area?

Given;

$ppt^m = 2.5\,cm$, Area (A) = $2000\,km^2$

Volume of rainfall occurs in the area, V = A × depth

$= 2000 \times 10^6\,m^2 \times \frac{2.5}{100}\,cm$

$= 500 \times 10^4\,m^3$ in 1 day.

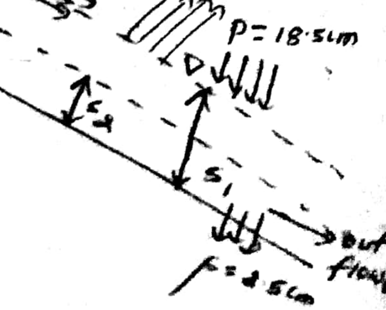
Hence,

Rate of Rainfall in that Area $= \frac{\text{Volume}}{\text{time}}$

$= \frac{500 \times 10^4}{24 \times 3600}\,\frac{m^3}{s}$

K.S. 1.3 Estimate the constant rate of withdrawl from a 1375 ha reservoir in a month of 30 days during which the reservoir level dropped by 0.75m in spite of an average inflow in to the reservoir of 0.5 Mm³/day. During the month the average seepage loss from the reservoir was 2.5 cm, total precipitation on the reservoir was 18.5 cm and the total evaporation was 9.5 cm.

Solution:-



$A = 1375\,ha = 1375 \times 10^4\,m^2$

Inflow (I) = $0.5\,Mm^3/day = 0.5 \times 10^6\,m^3/day$

Here,

$S_2 - S_1 = -\Delta S = -0.75\,m$.

Total depth of inflow in a 30 days of a month.

$$= 0.5\times10^6 \times 30 \times \frac{1}{1375\times10^4} \quad \left[depth = \frac{Volume}{Area}\right]$$

$= 1.0909\ m$

$= 109.09\ cm.$

Depth of rainfall in 30 days = 18.5 cm

" " Seepage " " " = 2.5 cm

" " Evaporation " " " = 9.5 cm.

Now, we know that;

$S_1 + [(P+I) - (O+\cancel{S}+E_v)] = S_2$.

$(18.5 + 109.09) - (O + 2.5 + 9.5) = S_2 - S_1 = -\Delta S$

$(18.5+109.09) - (O + 2.5 + 9.5) = -0.75\times10^2$

$O = 190.59\ cm.$

Total volume of withdrawl in 30 days;

= Area × depth.

$= 1375\times10^4 \times 1.9059\ m = 26206125\ m^3$

Rate of outflow from the reservoir $= \frac{Volume}{time}$

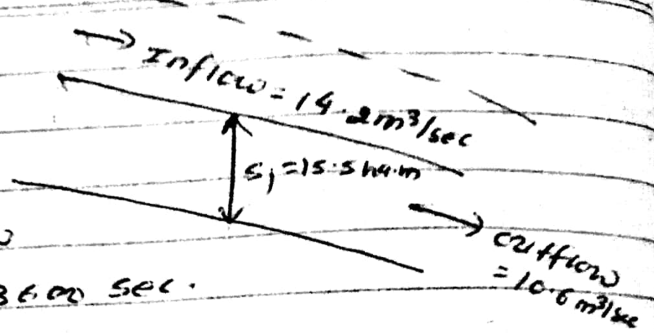
$$= \frac{26206125}{30\times24\times3600}$$

$= 10.11\ m^3/sec.$

Ans

K.S.14 A river reach had a flood wave passing through it. At a given instant the storage of water in the reach was estimated as 15.5 ha.m. What would be the storage in the reach after an interval of 3 hour if the average inflow and outflow during the time period are $14.2\ m^3/s$ and $10.6\ m^3/s$ respectively?

Solution;-



Total volume of inflow water $= 14.2\ m^3/s \times 3 \times 3600$ sec.
$= 153360\ m^3$.

Initial storage in the rivers $S_1 = 15.5 \times 10^4 m^3$

Total Volume of outflow water $= 10.6 \frac{m^3}{s} \times 3 \times 3600$ sec
$= 114480 m^3$.

Using water balance equation;
Initial storage + Total inflow − Total outflow = final storage
i.e. Final storage $= [15.5\times10^4 + 153360 - 114480]\ m^3$
$= 19.388$ ha.m

[Note:- change in storage in rivers $(\Delta S) = S_2 - S_1$]

K.S.1.5. A catchment has four sub-areas. The annual precipitation and evaporation from each of the sub areas are given below.
Assume that there is no change in the groundwater storage on an annual basis and calculate for the whole catchment the values of annual average (i) precipitation, and (ii) evaporation. What are the annual runoff coefficient for the sub-areas and for the total catchment taken as whole?

Sub-area	Area mm^2	Annual precipitation mm	Annual evaporation mm
A	10.7	1030	530
B	3.0	830	438
C	8.8	900	430
D	17.0	1300	600.

R.O. = ppt^n − Eva.

Solution:-

SubArea	Area mm^2	Annual ppt^n mm	Annual Evap. mm	Runoff.
A	10.7	1030	530	500
B	3.0	830	438	392
C	8.2	900	430	470
D	17.0	1300	600	700.

Total Area of catchment = 38.9 mm^2

Annual average precipitation, $\bar{P} = \frac{\Sigma A_i P_i}{\Sigma A_i}$

$$\bar{P} = \frac{[10.7\times1030 + 3.0\times830 + 8.2\times900 + 17.0\times1300]}{[10.7+3.0+8.2+17.0]}$$

$\bar{P} = 1105$ mm.

[or $\bar{P} = \frac{\Sigma P_i}{N}$ can also be used but above method is more suitable methods].

Total Annual average Evaporation, $\bar{E_v} = \frac{\Sigma E_{vi} A_i}{\Sigma A_i}$

$$\bar{E_v} = \frac{[10.7\times530 + 3.0\times438 + 8.2\times430 + 17.0\times600]}{[10.7+3.0+8.2+17.0]}$$

$\bar{E_v} = 532.4$ mm.

Now,

Let C be the Runoff coefficent, then $C = \left[\frac{R.O}{P}\right]$

∴ Runoff Coefficent for the Sub-Area A $= \left(\frac{500}{1030}\right) = 0.485$,

∴ Runoff Coefficent for the Sub-Area B $= \left(\frac{392}{830}\right) = 0.472$

∴ Runoff Coefficent for the Sub-Area C $= \left(\frac{470}{900}\right) = 0.522$

(14)

$\therefore$ Runoff coefficent for sub-Area D $= \left(\frac{700}{1300}\right) = 0.538$.

Hence, R.O. coefficent of the whole catchment;

$$\bar{C} = \frac{\Sigma A_i C_i}{\Sigma A_i} = \frac{10.7\times 0.485 + 3.0\times 0.472 + 8.2\times 0.522 + 17.0\times 0.538}{(10.7+3.0+8.2+17.0)}.$$

$\therefore \bar{C} = 0.514$ Ans//

[Note:- Average annual runoff coefficent of the catchment $\bar{C} = \left[\frac{\bar{R}}{\bar{P}}\right]$

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Chapter :- 3 - precipitation

Imp

Defination :-

Various form of water that reach the earth from the atmosphere is known as precipitation. the usual forms are rainfall, snowfall, hail, frost and dew.

precipitation is the return of atmospheric moisture to the ground in the form of solids or Liquids.

Imp

Forms of precipitation :-

1. Rainfall :- precipitation in the form of water drops of sizes larger than 0.5mm is termed as rain. Rainfall is classified as

(a) Light rain → Intensity ≤ 2.5 mm/hr.

(b) moderate rain → Intensity > 2.5 mm/hr and < 7.5 mm/hr

(c) Heavy rain → Intensity > 7.5 mm/hr.

2. snow :- snow is the another important form of precipitation. snow consists of ~~ice~~ ice crystals and density varying from 0.06 to 0.15 gm/cm³. snow occurs only in the Himalayan regions.

3. Drizzle :- This is a form of precipitation consisting of water droplets of diameter less than 0.5mm with the intensity less than 1mm/hr.

4. Glaze :- When rain or drizzle comes in contact with cold ground at around 0°c, the water drops freeze to form an ice coating called glaze.

5. Sleet :- Sleet denotes precipitation of snow and rain simultaneously, which form when rainfall through air at subfreezing temperature.

6. Hails :- These are balls or irregular lumps of ice of size more than 8 mm formed by repeated freezing and melting.

Imp. Types of precipitation :-

Following are the types of precipitation based on lifting mechanism.

1. Convective precipitation
2. Orographic precipitation
3. Cyclonic precipitation

1. Convective precipitation :-

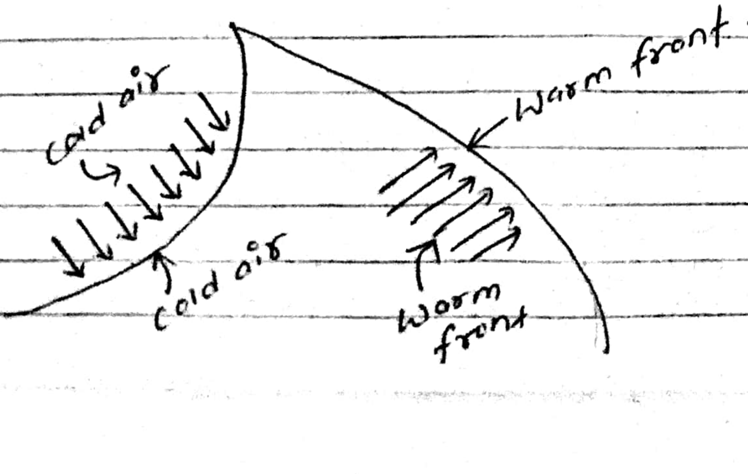
This is due to the lifting of warm air which is lighter than the surrounding. Air which is warmer than the surrounding air due to localised heating rises because of lesser density and cooler surrounding air take up its place. The warm air continues to rise undergoes cooling and results in precipitation.

2. Orographic precipitation :-

It is the most important precipitation and is responsible for most of heavy rains. The moist airmasses get lifted-up to higher altitude due to the presence of some natural topographic barriers like mountains and consequently undergoes cooling, condensation and precipitation. The greatest amount

of precipitation fall on the Windward side and leeward side has very little precipitation.

3. Cyclonic precipitation :-
This is the precipitation associated with cyclones or moving masses of air and involves the presence of low pressure. this is further sub divided into 2 catagories.
(a) Non-Frontal cyclonic precipitation : In this, a low pressure area develops, low pressure area is a region where the atmospheric pressure is lower than that of surrounding locations. The air from surrounding converges laterally towards the low pressure area. This result in lifting of air and hence cooling. It may result in precipitation.
(b) Frontal cyclonic precipitation : FRONT is a barrier region between two air masses having different temperature, densities, moisture, current etc. If a warm and moist air gets lifted, cooled and may result in precipitation. The precipitation may extend for 500 km ahead of the front i.e, the colder air region. If a moving mass of cold air forces a warm air mass upwards, we can expect a cold from precipitation.



Criteria for selecting raingauge site:-

1. The ground must be level and in the open and the instrument must present a horizontal catch surface.
2. The gauge must be set as near the ground as possible to reduced wind effect but it must be sufficiently high to prevent splashing, flooding etc.
3. The instrument must be surrounded by an open fenced area of at least 5.5m x 5.5m. No object should be nearer to the instrument than 30m or twice the height of the obstruction.

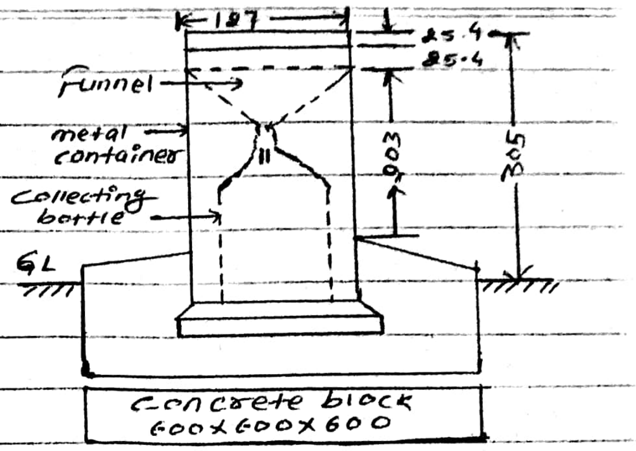
measurement of precipitation :-

precipitation is expressed in terms of the depth to which rainfall water would stand on an area if all the rain were collected. The instrument used for measurement of rainfall is called Rain gauge. Term such as pluviometer, ombrometer and hyetometer are also sometimes used to designate a raingauge.

Types of Raingauge.

1. Non-recording types.

The gauge which is read manually is called non-recording gauge. These raingauge do not record the depth of rainfall but only collect rainfall. Symon's rain gauge is the usual non-recording type of the rain gauge. It gives the total rainfall that has occured at a particular period.



It is essentially consists of a circular collecting area 127mm in diameter connected to a funnel. The funnel discharges the rainfall into a receving vessel. The rainfall collected in the vessel in measured by dipstick or measuring cylinder which give the depth of rainfall.

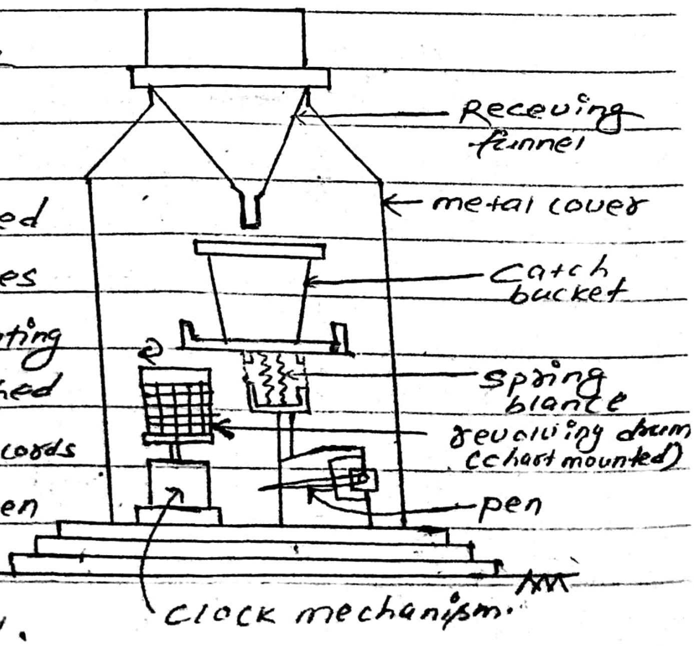
Fig:- Symon's raingauge.

2. Recording rain gauge :-

These are rain gauge which give automatic rainfall record in the form of a pen mounted on a clock driven chart.

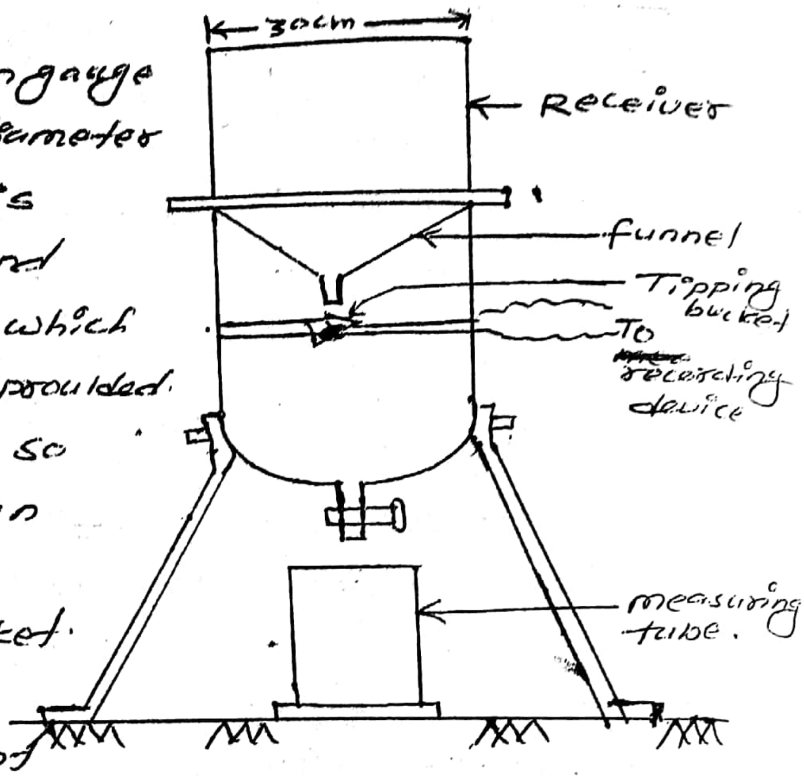
(a) Weighing bucket raingauge :-

This is the most common type of recording or automatic rain gauge. The construction of rain gauge is shown below.



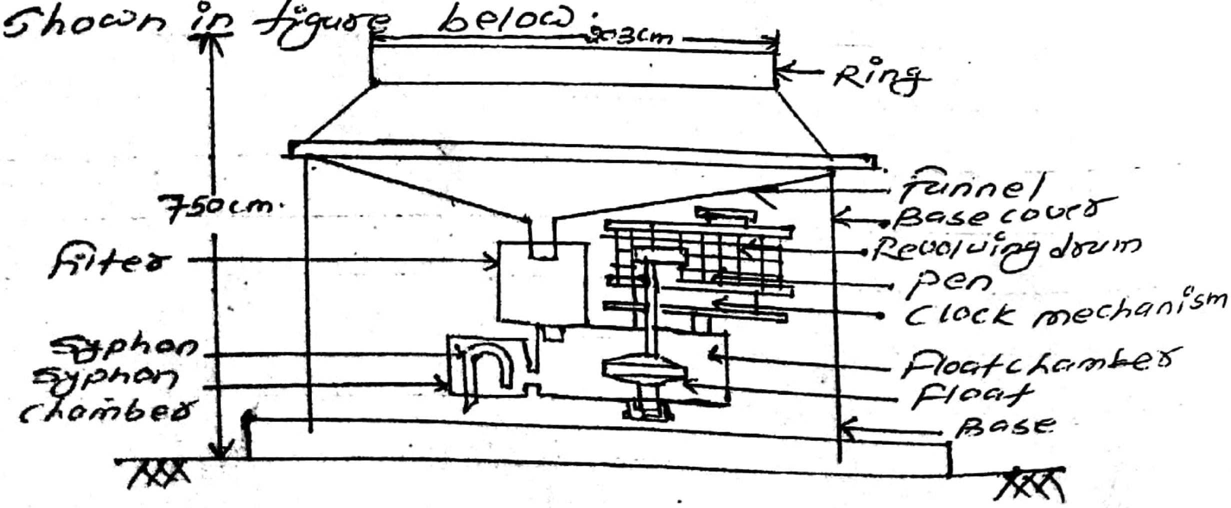
It consists of Receving bucket supported by a spring or lever. The receving bucket is pushed down due to the increases in weight (due to accumulating rainfall). The pen attached to the arm continously records the weight on a clock driven chart. The chart obtained from these rain gauge is a mass curve of rainfall.

(b) Tipping bucket raingauge :-



Tipping bucket raingauge consists of 30mm diameter receiver. A funnel is provided at the end of receiver under which pair of buckets is provided. These buckets are so balanced that when 0.25mm of rainfall collects in one bucket. Tipping of bucket cause the movement of a pen to mark on clock driven drums carrying a record sheet. This is useful in remote area.

(c) Syphon or float type rain gauge.
This is also called integrating raingauge as it depicts an integrated graph of rainfall with respect to time. It uses the syphon mechanism to empty the rainwater collected in the float chamber. The construction of these raingauge is shown in figure below.



A receiver and funnel arrangement drain the rainfall in to a container, in which a float mechanism at the bottom is provided. The float aries as the Water level rises in the container and its movement is recorded by pen arm attached to the float mechanism. When the water level uses above the crest of syphon, the syphon comes in to operation and release the water.

Estimation of missing Rainfall data:-

1. Arithmetic average method

If the normal annual precipitation at various stations are with in about 10% of the normal annual precipitation at station x, then missing data is estimated by simple arithmetic average method.

$$P_x = \frac{1}{m}\left[P_1 + P_2 + P_3 + \cdots\cdots + P_m\right]$$

Where;

$P_1, P_2, P_3, \cdots\cdots P_m$ = Rainfall of surrounding station.

P_x = Rainfall of missing station.

m = no. of surrounding station.

2. Normal ratio method :-

If the normal precipitation vary considerably (more than 10%) then P_x is estimated by normal ratio method, gives P_x as

$$P_x = \frac{N_x}{m}\left[\frac{P_1}{N_1} + \frac{P_2}{N_2} + \cdots\cdots + \frac{P_m}{N_m}\right]$$

Where; N_x = Normal annual rainfall at x.

P_x = Rainfall of missing station.

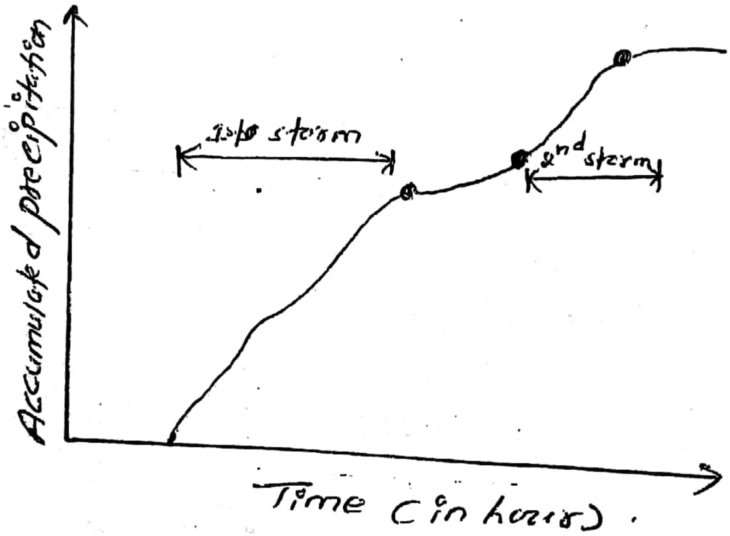
$P_1, P_2, \cdots\cdots P_m$ = precipitation at surrounding station.

m = no. of Surrounding station.

Presentation of Rainfall data :-

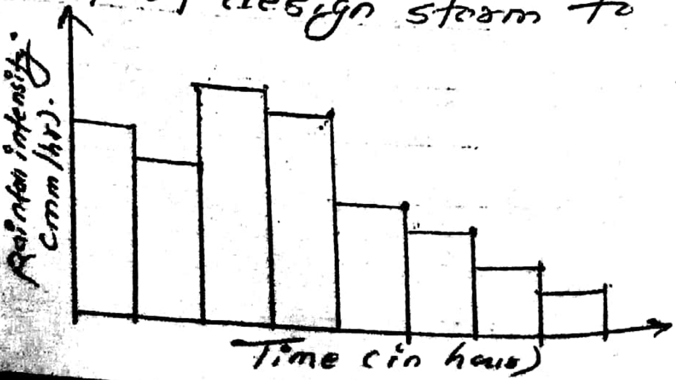
1. mass curve

The mass curve of rainfall is a plot of the accumulated precipitation at a station as ordinate and time as abscissa in chronological order. mass curve of rainfall are very useful in extracting the information on the duration and magnitude of a storm.



2. Hyetograph :-

A Hyetograph is a plot of the intensity of rainfall against the time interval in the form of bar graph. The hyetograph is derived from mass curve. The area under hyetograph represents the total precipitation received in the period. It is important in the development of design storm to predect extrem flood.



Estimation of mean Rainfall over an Area :-

1. Arthmetic mean method :-

This is the simplest method in which average depth of rainfall is obtained by obtaining the sum of the depth of rainfall (say, P_1, P_2, P_3, P_4 ------ P_n) measured at station 1, 2, 3, ------ n and dividing the sum by the total number of station i.e. n, Thus;

$$\bar{P} = \frac{P_1 + P_2 + P_3 + \cdots\cdots + P_n}{n} = \frac{1}{n}\sum_{i=1}^{n} P_i.$$

This method is suitable if the rain gauge station are uniformly distributed over the entire area and the rainfall variation in the area is not large.

2: Theissen polygon method :-

In this method the rainfall recorded at each station is given a weightage on the basis of an area closest to the station.

procedure :-

→ Draw the map of catchment area and locate the position of rainfall station (P_1, P_2, P_3 ------)

→ Join the adjacent rainfall station with straight Lines, forming triangles.

→ Draw perpendicular bisector on each of the Lines joining adjacent rain gauge stations.

→ There will be number of polygons and each polygon with in itself, will have onlyone raingauge station. measure area of each polygon.

→ multiply the area of each polygon by the raingauge value of the enclosed station.

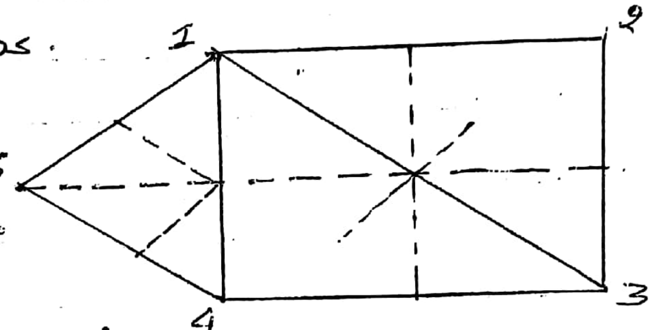
$$\bar{P} = \frac{P_1A_1 + P_2A_2 + \cdots + P_nA_n}{A_1 + A_2 + \cdots + A_n} = \frac{1}{A}\sum_{i=1}^{n} P_iA_i.$$

Where;

$P_1, P_2 \cdots P_n$ = precipitation at various stations.

$A_1, A_2 \cdots A_n$ = respective area of Thiessen polygon

n = no. of stations.



Where,

— = Line joining adjacent raingauge station

- - - - = perpendicular bisector.

3. Isohyetal method:-

An isohyetal is a line joing point of equal rainfall magnitude. It is considered the most accurate method since it considers orographic effects.

Steps :-

→ Draw the map of the catchment area and mark the raingauge station

→ mark the depth of rainfall at each raingauge station.

→ prepare the isohyetal map.

→ Compute the area between successive ~~isohyetal~~ isohyets and multiplying by the average rainfall between the isohyet.

→ Use formula to calculate average rainfall

$$\bar{P} = \frac{\sum A_i \frac{P_i + P_{i+1}}{2}}{A}$$

Where;

$\bar{P}$ = Average precipitation for the area.
P_i, P_{i+1} = precipitation of i and i+1 isohyet.
A_i = Area between two successive isohyet.
A = Total catchment area.

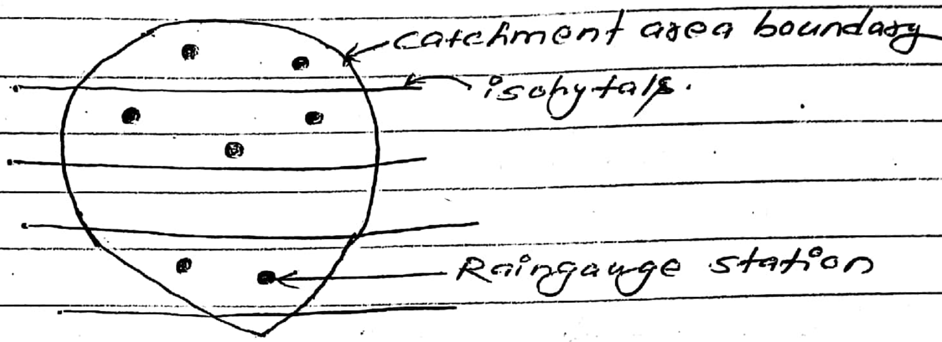
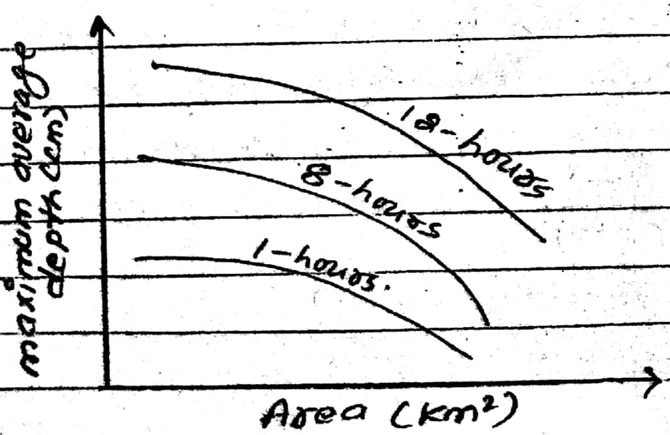


Fig :- Isohyetal method.

Depth-Area-Duration (DAD) curve :-

Depth-Area-Duration curves is the plot of accumulated average precipitation versus area for different duration of a storm period. In DAD-curve, area is taken on x-axis, average depth on y-axis and duration of rainfall as third parameter. Depth-area-duration analysis of a storm is performed to estimate the maximum amounts of precipitation for different durations and over different areas.



first, all the major storms that have occured in the region are considered. Isohyetal ~~map~~ map and mass curve of the storm are prepared. A depth-area curve of a given duration of the storm is prepared. then from a study of the mass curve of rainfall, various durations and the maximum depth of rainfall in these duration are noted. The maximum depth-area curve for a given duration 'D' is prepared by assuming the area distribution of rainfall for smaller duration to be similar to the total storm. the procedure is then repeated for different storms and the envelope curve of maximum depth-area for duration 'D' is obtained. A similar procedure for various values of 'D' results in a family of envelope curves of maximum depth vs area, with duration as third parameter.

Intensity-Duration-Frequency (IDF) Analysis:-

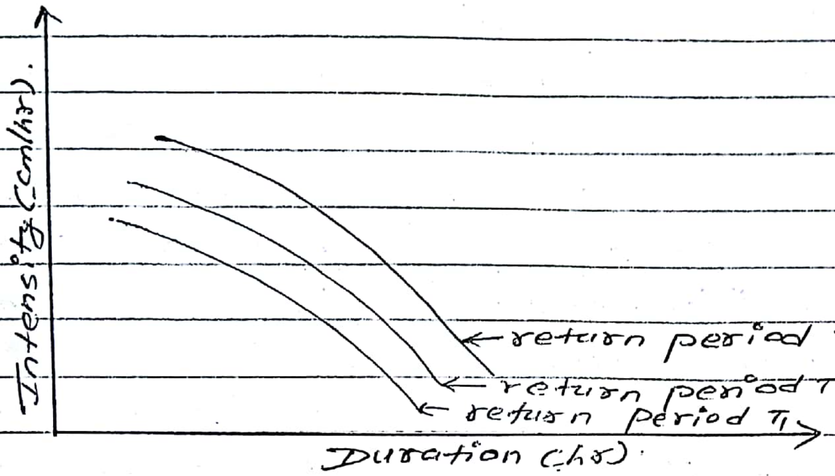
The curve that shows the inter-dependency between (cm/hr), duration (hr) and return period (year) is called IDF curve. In IDF curve, duration is plotted as abscissa, intensity as ordinate and series of a curve, one of each return period as the third parameter. the relation can be expressed in general forms as:

$$i = \frac{KT^x}{(D+a)^n}$$

where; i = intensity (cm/hr.)

D = duration (hours)

K_1, x_1, a_1, n - are constant for given catchment.



Procedure to calculate the intensity - duration - Frequency relationship for a given storm.

→ M no. of significant and heavy storm in a particular year Y_1 are selected, each of which are analysed for maximum intensity duration relationship.

→ This gives the set of maximum intensity I_m as a function of duration for the year Y_1.

→ The procedure is repeated for the N = year of record to obtain maximum intensity $I_m(D_j)_k$ for all $j = 1$ to M and $k = 1$ to N

→ Each record of $I_m(D_j)_k$ for $k = 1$ to N constitutes a time series which can be analysed to obtain frequencies of occurance of various $I_m(D_j)$ values. Thus there will be M times series generated.

→ The results are plotted as maximum intensity vs return period with the duration as the third parameters.

Test of Consistency of Rainfall Record:

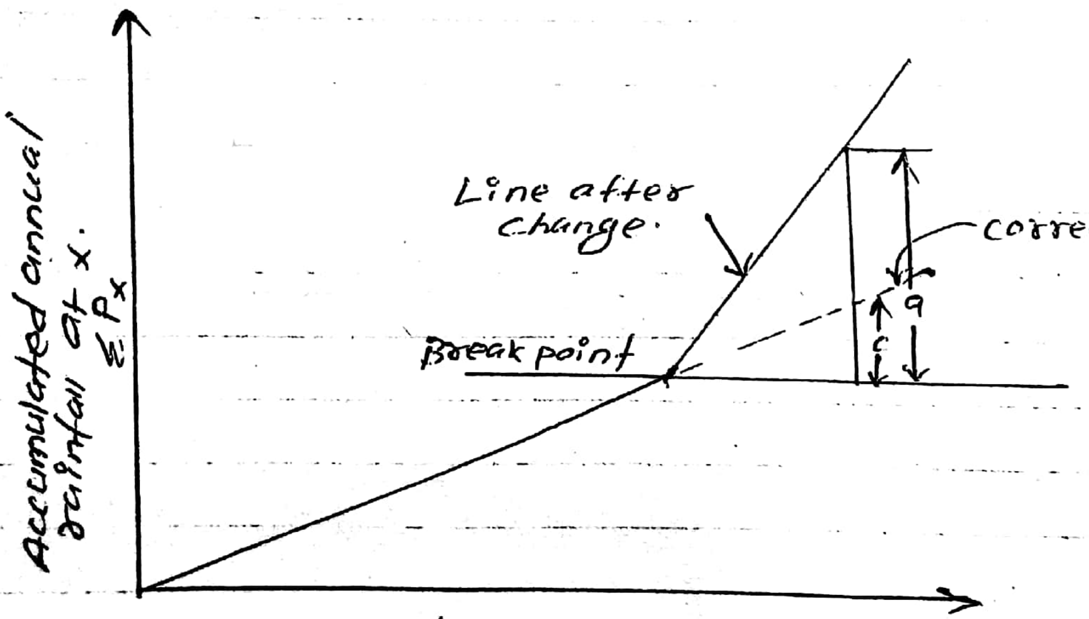
or Double mass curve

Imp

The double-mass analysis is used to detect if data

at a site have been subjected to a significant change in magnitude due to external forces such as problems with instrument, observation or recording conditions.

Double mass curve is the plot of accumulated annual rainfall at a particular station versus the accumulated annual values of mean rainfall of surrounding stations. If the data are consistent the double mass curve will be a straight line of constant slope. If the data is not constant, a break in the double mass curve will be apparent.



procedure :-

→ A group of 5 to 10 base station in the neighbourhood of the problem station x is selected.

→ The data of the annual rainfall of the station x and also the average rainfall of the group of base station covering a long period is arranged in reverse chronological order (i.e, the latest record as the first entry and the oldest record as the last entry).

→ The accumulated precipitation of the station x (i.e., ΣP_x) and the accumulated values of the average of the group of base station (i.e., ΣP_{av}) are calculated.

→ Values of ΣP_x and ΣP_{ave} are plotted for Various consecutive time period. ΣP_x is plotted in y-axis and ΣP_{avg} in x-axis.

→ The break in the slop of the resulting plot indicates a change in the precipitation ~~regime~~ regime of station x. The precipitation values at station x beyond the change of regime is corrected by using the relation;

$$P_{cx} = P_x \cdot \frac{M_c}{M_a} \Rightarrow P_{cx} = P_x \cdot \frac{c}{a}$$

Where;

P_{cx} = Corrected precipitation for station x.

P_x = original precipitation of station x.

M_a = original slope of double mass curve

M_c = Corrected slope of the double mass curve.

Numerical parts :-

LAB 2002 Q.No.1. The normal annual pptn at station A, B, C & D in the basin are 80.97, 67.59, 76.8 and 92.01 cm. respectively. In the year 1975, the station D was inoperative and the station A, B, C recorded annual pptn of 91.11, 72.23, 79.89 cm respectively. Estimate the rainfall at station D in the year.

Solution; Given:-

The normal annual pptn at station A, (N_A) = 80.97 cm

The normal annual pptn at station B, (N_B) = 67.59 cm

(30)

The normal annual pptⁿ at station C, $P(N_c) = 76.8cm$
The normal annual pptⁿ at station D, $(N_D) = 92.01cm$

In the year 1975

Annual pptⁿ of station A $(P_A) = 91.11cm$
" " " " B $(P_B) = 72.23cm$
" " " " C $(P_C) = 79.89cm$
" " " " D $(P_D) = ?$

Airthmetic mean method

$$P_D = \frac{P_A + P_B + P_C}{3} = \frac{91.11 + 72.23 + 79.89}{3} = 81.076 \text{ cm.}$$

Check :-

$$\frac{N_D - N_A}{N_D} * 100 = \frac{92.01 - 80.97}{92.01} * 100 = 11.99 \%$$

$$\frac{N_D - N_B}{N_D} * 100 = \frac{92.01 - 67.59}{92.01} * 100 = 26.54 \%$$

$$\frac{N_D - N_C}{N_D} * 100 = \frac{92.01 - 76.8}{92.01} * 100 = 16.53 \%$$

Here, The normal annual pptⁿ of station A, B and C exceeds 10 % with normal annual pptⁿ of station D. so we use the Normal ratio method.

$$P_D = \frac{N_D}{(N-1)} \left[\frac{P_A}{N_A} + \frac{P_B}{N_B} + \frac{P_C}{N_C} \right]$$

$$P_D = \frac{92.01}{(4-1)} \left[\frac{91.11}{80.97} + \frac{72.23}{67.59} + \frac{79.89}{76.8} \right]$$

$P_D = 99.19$ cm.

∴ The annual pptⁿ of station D, $P_D = 99.19$ cm

Ans.

Assignment no. 2 Q.1

During a storm, the estimated missing pptⁿ for the Station X was found to be 220mm and for the surrounding stations A, B, C and D the ratios of their normal pptⁿ to their storm pptⁿ were found to be 0.88, 0.91, 0.94 and 0.97 respectively. Calculate the normal ppt for station X.

Solution;- Given;-

The estimated missing pptⁿ for station X, (P_x) = 220mm

Here, we denote Normal pptⁿ as N,

So, Ratio of normal pptⁿ to their storm ppt, for station A, B, C and D are;

$$\frac{N_A}{P_A} = 0.88, \quad \frac{N_B}{P_B} = 0.91, \quad \frac{N_C}{P_C} = 0.94 \quad \& \quad \frac{N_D}{P_D} = 0.97.$$

The Normal pptⁿ of X, (N_x) = ?

Now, we know that;

$$P_x = \frac{N_x}{N-1}\left[\frac{P_A}{N_A} + \frac{P_B}{N_B} + \frac{P_C}{N_C} + \frac{P_D}{N_D}\right]$$

$$P_x = \frac{N_x}{N-1}\left[\frac{1}{\left(\frac{N_A}{P_A}\right)} + \frac{1}{\left(\frac{N_B}{P_B}\right)} + \frac{1}{\left(\frac{N_C}{P_C}\right)} + \frac{1}{\left(\frac{N_D}{P_D}\right)}\right]$$

$$220 = \frac{N_x}{5-1}\left[\frac{1}{0.88} + \frac{1}{0.91} + \frac{1}{0.94} + \frac{1}{0.97}\right]$$

$\therefore N_x = 203.23$ mm Ans

Assignment no. 2 Q.3

Compute the rainfall at the station X from the following data:

Station	X	A	B	C
Storm rainfall (cm)	?	12.5	14.5	16.9
Annual rainfall (cm):	115	125	145	130.

Solution:- Given:-

The storm rainfall at station X (P_x) = ?

" " " " " A (P_A) = 12.5 cm

" " " " " B (P_B) = 14.5 cm

" " " " " C (P_C) = 16.9 cm

The annual rainfall at station X (N_x) = 115 cm

" " " " " A (N_A) = 125 cm

" " " " " B (N_B) = 145 cm

" " " " " C (N_C) = 130 cm.

Arthmetic Average method :-

$$P_x = \frac{P_A + P_B + P_C}{3} = \frac{12.5 + 14.5 + 16.9}{3} = 14.63 \text{ cm}.$$

Check;

$$\frac{N_x - N_A}{N_x} * 100\% = \frac{115 - 125}{115} * 100 = 8.69\%$$

$$\frac{N_x - N_B}{N_x} * 100\% = \frac{115 - 145}{115} * 100 = 26.08\%$$

$$\frac{N_x - N_C}{N_x} * 100\% = \frac{115 - 130}{115} * 100 = 13.04\%$$

Here, The annual rainfall at station B and C exceeds 10% with the annual rainfall of station X. so we use the Normal ratio method.

$$P_x = \frac{N_x}{N-1}\left[\frac{P_A}{N_A} + \frac{P_B}{N_B} + \frac{P_C}{N_C}\right]$$

$$P_x = \frac{115}{(4-1)}\left[\frac{12.5}{125} + \frac{14.5}{145} + \frac{16.9}{130}\right]$$

$\therefore$ $P_x = 12.65$ cm **Ans**

[Note:- Storm/annual r.f → a.g.r / Normal annual r.f → an]

A catchment has six raingauge stations. In a year, the annual rainfall recorded by the gauges are as follows:

Station	A	B	C	D	E	F
Rainfall (cm)	82.6	102.9	180.3	110.3	98.8	136.7

For 10% of error in the estimation of the mean rainfall, calculate the optimum number of stations in the catchment.

Solution:-

$$\text{mean}(\bar{P}) = \frac{(82.6+102.9+180.3+110.3+98.8+136.7)}{6}$$

$$= 118.6$$

$$\text{Standard deviation } (\sigma) = \sqrt{\frac{(P_i-\bar{P})^2}{n-1}}$$

$$= \sqrt{\frac{(82.6-118.6)^2+(102.9-118.6)^2+\cdots}{6-1}}$$

$$= 35.04$$

$$\text{coefficent of variance } (C_v) = \frac{\sigma}{\bar{P}} * 100$$

$$= \frac{35.04}{118.6} * 100$$

$$= 29.54$$

Error in Estimation $(E) = 10\%$

$\therefore$ optimum number of station $(N) = \left(\frac{C_v}{E}\right)^2$

$$= \left(\frac{29.54}{10}\right)^2 = 8.7 \text{ say } 9 \text{ stations}$$

$\therefore$ Number of additional station $= 9-6$

$= 3$ stations.

H M Raghunath. P.6

For the basin show in fig. P.2.23, the normal annual rainfall depths recorded and the isohyetals are given. Determine the optimum number of rain-gauge station to be established in the basin if it is desired to limit the error in the mean value of rainfall to 10%. Indicate how you are going to distribute the additional rain gauge stations required if any. What is the percentage accuracy of the existing network in the estimation of the average depth of rainfall over the basin. The area between the isohyetals are given below.

Zone	I	II	III	IV	V	VI	Total
Area(km^2):	63	278	389	220	55	33	1038.

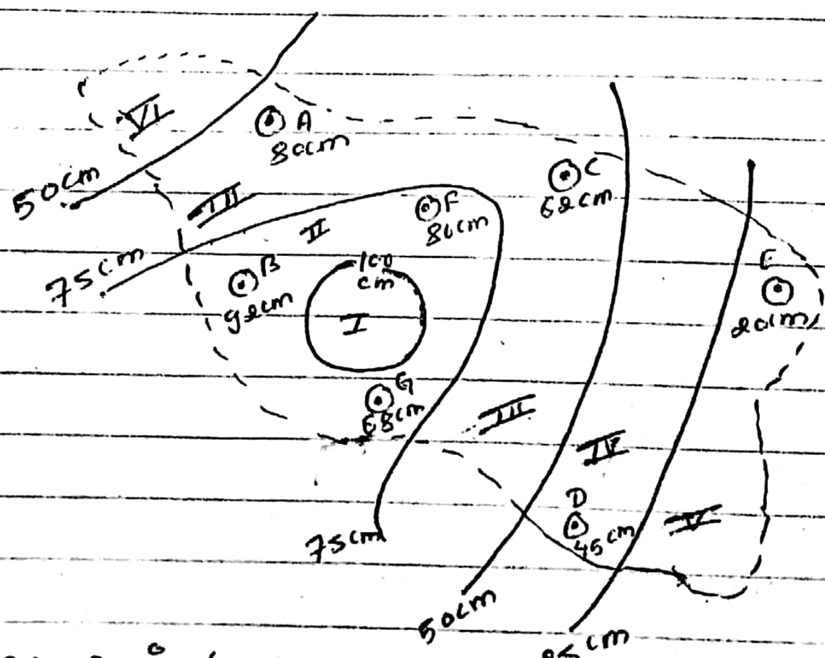


fig P2.23 isohyetal map.

Solution:-

Annual rainfall of whole catchment area;

$$\bar{P} = \frac{92+60+68+86+45+20}{7} = 61.86cm.$$

optimum No. of raingauge station, $N = \left(\frac{CV}{\% E}\right)$.

Standard deviation $\sigma_{n-1} = \sqrt{\dfrac{\Sigma(P-\bar{P})^2}{n-1}} = 24.38.$

coefficent of variance (CV) $= \dfrac{\sigma_{n-1}}{\bar{P}} = \dfrac{24.38}{61.86} = 0.39.$

Here; $N = \left(\dfrac{CV}{\%E}\right)^2$

% of Error in the average rainfall in the whole catchment area (%E) $= \left(\dfrac{CV}{\sqrt{N}}\right)$ at a Existing conditions.

$\%E = \dfrac{CV}{\sqrt{n}}$, ~~N~~ $n=7.$ & $N=n=7$

$= \dfrac{0.39}{\sqrt{7}}$

$= 0.15$

$= 0.15 * 100 = 15\%$

Now, % of accuracy in the average pptn $= 100 - \%E$
$= (100-15)\% = 85\%$

For 10% of Error optimum number of rain gauge, $N = \left(\dfrac{CV}{\%E}\right)^2$

$= \left(\dfrac{0.39}{0.1}\right)^2 = 15.21 \approx 16.$

Hence additional Number of raingauge station Required = optimum no. of station - Existing no. of station

$= 16 - 7$

$= 9.$

$\therefore$ Additional number of raingauge station is 9. Ans

~~Standard~~

Distribution of total no. of raingauge station

Zone	I	II	III	IV	V	VI	Total
No. of station req.	0.97	4.29	6	3.39	0.85	0.5	
Rounded as Req. st.	1	4	6	3	1	1	16
Exsting st.	—	3	2	1	1	—	7
additional st.	1	1	4	2	—	1	9.

Here;

Total Area = 1038 km^2.

In 1038 km^2, 16 station is Required.

In 63 km^2, $\left(\frac{16}{1038} \times 63\right)$ station is Required

Similarly all zone is calculated and fill up above table.

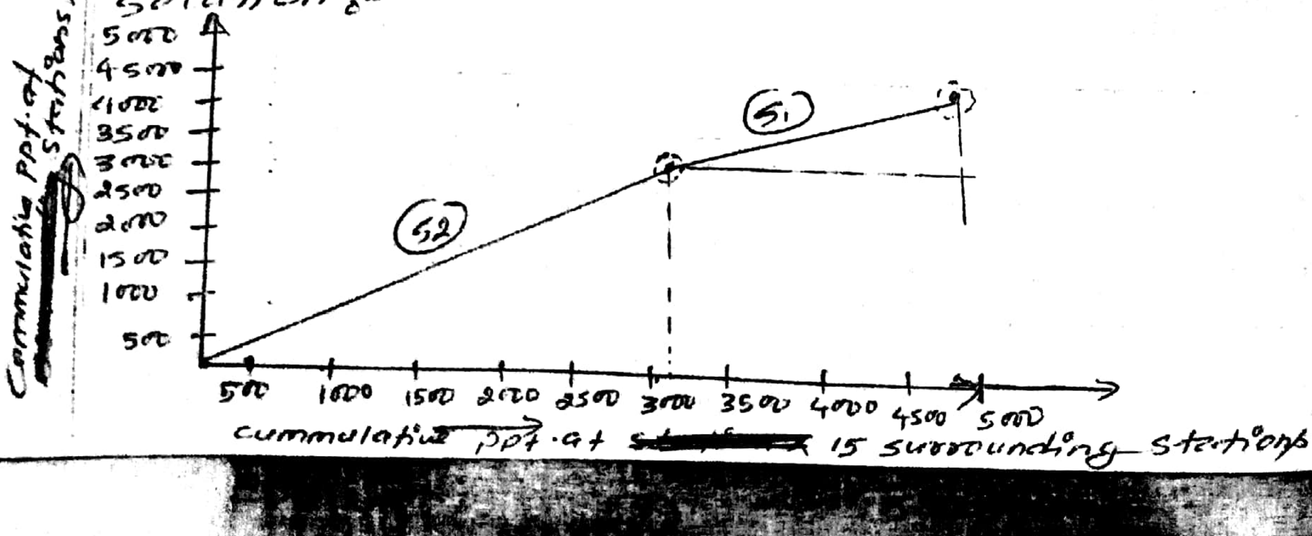
Assignment no. 2. Q.1

The cumulative annual pptn at station x and that of average at 15 surrounding stations from years 1961 to 1995 are computed as follows

period (years)	Cummulative ppt. at Station x.	Commulative ppt. at 15 surrounding station
1961-80	4560 cm	4332 cm
1981-95	3150 cm	3210 cm

Compute the mean annual ppt. for station x at its 1995 ~~site~~ and 1965 site for the entire 35 years with the data adjusted for the change regime

Solution:-



Slope at 95 site $(s_2) = \left(\frac{3150}{3210}\right) = 0.98.$

Slope at 65 site $(s_1) = \frac{4560}{4332} = 1.05.$

Cummulative ~~Annual~~ rainfall of st. x with adjusted data in 1965 site $= 3150 \times \frac{1.05}{0.98} = 3375$ cm.

Average annual rainfall for st. x $= \frac{4560+3375}{35}$

$= 226.89$ cm. Ans.

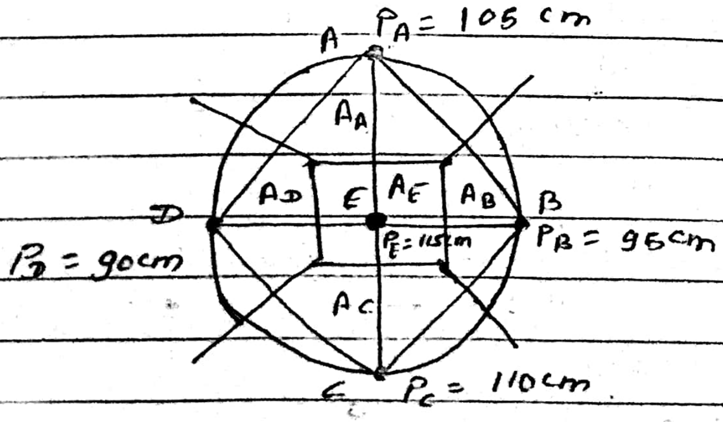
Cummulative rainfall of st. x with adjusted data in 1995 site $= 4560 \times \frac{0.98}{1.05} = 4256$ cm.

Average annual rainfall of st. x in 1995 site;

$= \left(\frac{3150+4256}{35}\right)$ cm $= 211.38$ cm. Ans

[Note:- Average annual rainfall at st. x without adjusted data $= \left[\frac{4560+3150}{35}\right] = 220.29$ cm.]

Estimate the average annual rainfall over an catchment of 4 cm dia. as shown in fig. below.



Solution:-

Total Area of the catchment $= \left(\frac{\pi d^2}{4}\right) = \frac{\pi}{4} \times 4^2 = 12.56$ cm^2

$A_E = 2cm \times 2cm = 4cm^2$

Here, $A_A = A_B = A_C = A_D = \left[\frac{A - A_E}{4}\right]$

$= \left[\frac{12.56 - 4}{4}\right] = 2.14 cm^2.$

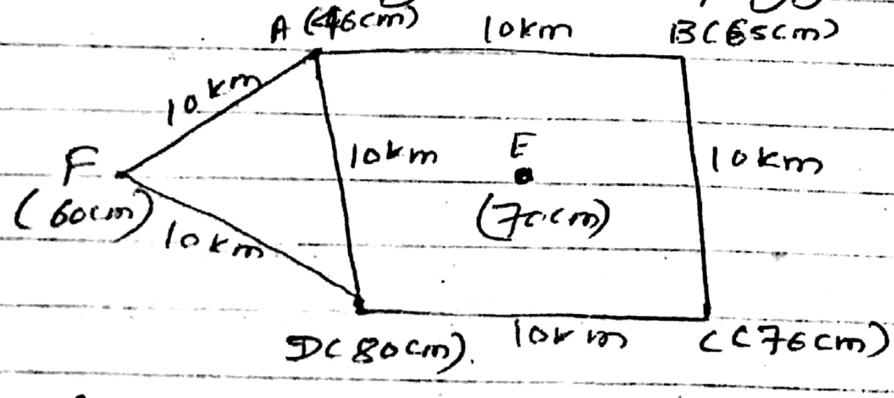
From Theissen polygon method;

$\bar{P} = \frac{P_A A_A + P_B A_B + P_C A_C + P_D A_D + P_E A_E}{A_A + A_B + A_C + A_D + A_E}.$

$\bar{P} = \frac{105 \times 2.14 + 95 \times 2.14 + 110 \times 2.14 + 90 \times 2.14 + 115 \times 4}{2.14 + 2.14 + 2.14 + 2.14 + 4}.$

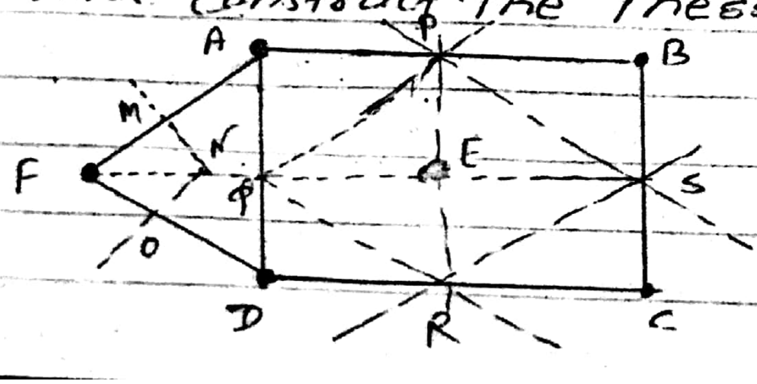
$\bar{P} = 105.28$ cm Ans

The area shown in figures is composed of a square plus an equilateral triangular plot of side 10km. The annual precipitation at the rain gauge stations located at the four corners and center of the square plot and apex of the triangular plot are indicated in figures. Find the mean precipitation over the area by Thiessen polygon method.



Solution:-

Here, we have construct the Thessien polygon;



The Area of square ABCD = $10 \times 10 = 100 km^2$

AP = AQ = 5 km ∴ $PQ = \sqrt{5^2+5^2} = \sqrt{50} = 5\sqrt{2}$ km.

∴ Area of inner square PQRS = $5\sqrt{2} \times 5\sqrt{2} = 50 km^2$

The area of equilateral traingle = $\frac{\sqrt{3}}{4}L^2 = \frac{\sqrt{3}}{4} \times 10^2 = 43.3 km^2$

Now,

Area of polygon for a station A is;

$= $ Area of ΔAPQ + Area of AQNMA

$= \frac{1}{2} \times 5 \times 5 + \frac{1}{3} \times 43.3$

$= 26.93 km^2$.

For, B = Area of $\Delta PSB = \frac{1}{2} \times 5 \times 5 = 12.5 km^2$

For, C = Area of $\Delta RCS = \frac{1}{2} \times 5 \times 5 = 12.5 km^2$.

For, D = Area of ΔRDQ + Area of DQNOD.

$= \frac{1}{2} \times 5 \times 5 + \frac{1}{3} \times 43.3$

$= 26.93 km^2$.

For, F = Area of FMNOF $= \frac{1}{3} \times 43.3 = 14.4 km^2$

For, E = Area of square PQRS = $50 km^2$.

∴ Total Area (A) = $143.26 km^2$.

∴ Mean precipitation ($\bar{P}$);

$= \frac{(26.93 \times 46 + 12.5 \times 65 + 12.5 \times 76 + 26.93 \times 80 + 14.4 \times 60 + 50 \times 70)}{143.26}$

$= 66.45$ cm.

Subbamappa 5.53.12.9

Following data are from a self-recording raingauge during a storm.

Time from begining of storm (minutes)	10	20	30	40	50	60	70	80	90
Accumulated rainfall (mm).	19	41	48	68	91	124	152	160	166

(a) Draw the hyetograph of the storm and mass curve of pptn.

(b) obtain the value of max m intensity of this storm for a various duration & plot a curve of maxm intensity Vs duration.

Solution:-

Time (min)	Cummulative rainfall (mm)	Incremental rainfall (mm)	Intensity (mm/hr)
10	19	19	114
20	41	22	132
30	48	7	42
40	69	20	120
50	81	23	138
60	124	33	198
70	152	28	168
80	160	8	48
90	166	6	36.

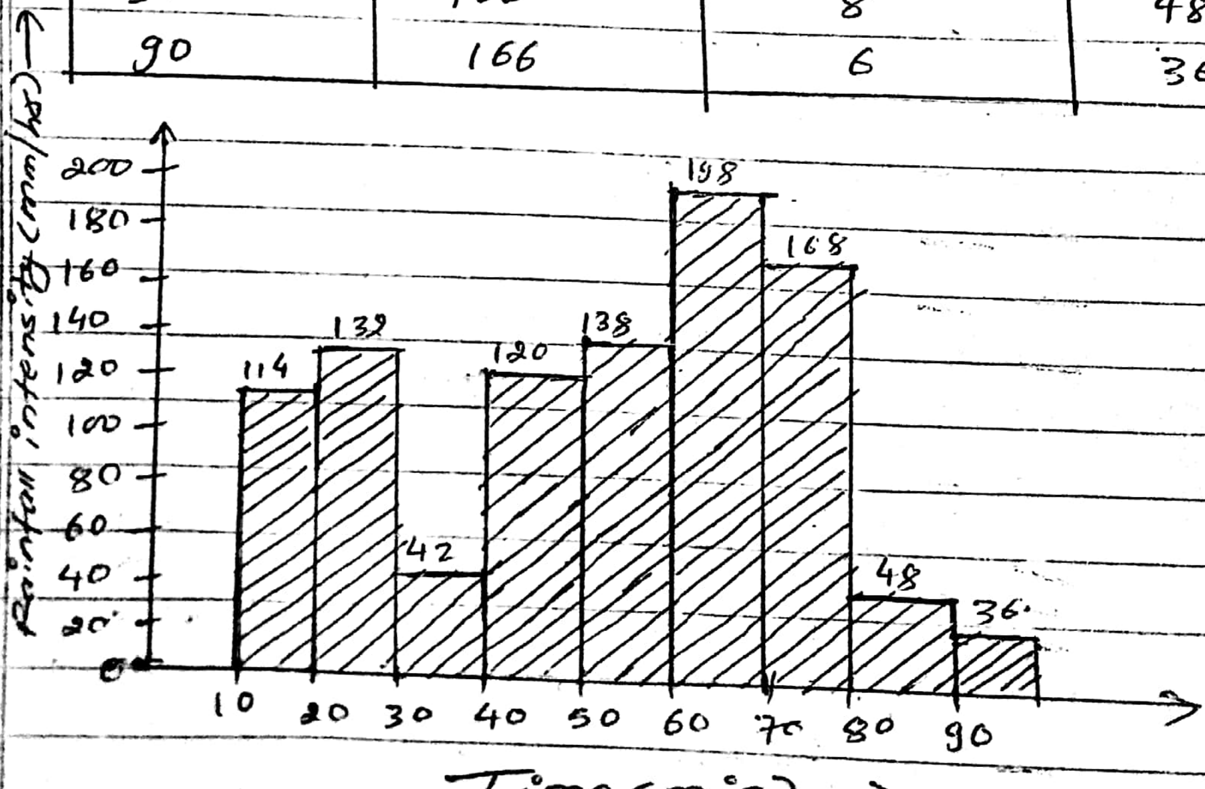


fig :- Hyetograph.

mass curve → Cummulative rainfall Vs Time.

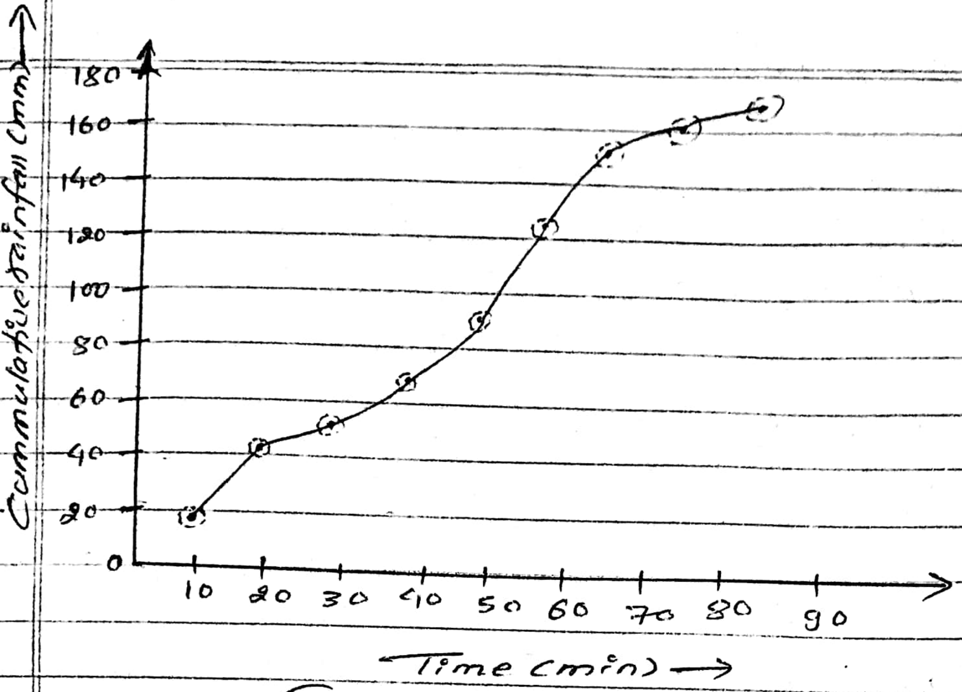


Fig :- mass curve of rainfall.

Time (min)	Rainfall depth (mm) for various durations								
	Δt=10 min	Δt=20 min	Δt=30 min	Δt=40 min	Δt=50 min	Δt=60 min	Δt=70 min	Δt=80 min	Δt=90 min
10	19								
20	22	41							
30	7	29	48						
40	20	27	49	68					
50	23	43	50	72	91				
60	33	56	76	83	105	124			
70	28	61	84	104	111	133	152		
80	8	36	69	92	112	119	141	160	
90	6	14	42	75	98	118	118	147	166

maximum rainfall and corresponding intensity for different duration.

Duration (min)	10	20	30	40	50	60	70	80	90
max Depth (mm)	33	61	84	104	112	133	152	160	166
max. intensity (mm/hr.)	198	183	168	156	134.4	133	130.3	120	110.7

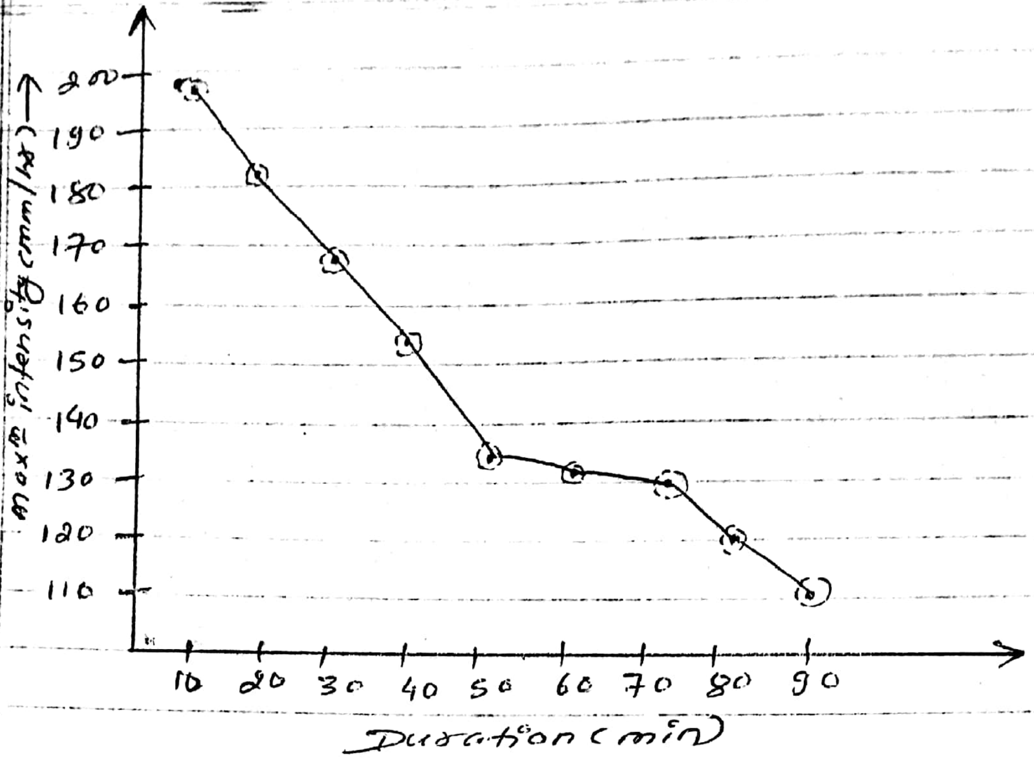


Fig:- max^m intensity duration curve.

[Note :- maximum ~~duration~~ depth duration curve ⇒ Duration Vs maximum depth]

2071 Chaitra

For a drainage basin of 600 km^2, isohyetals drawn for a storm gave the following. Estimate the average depth of precipitation over the catchment.

Isohyetal interval (cm)	15-12	12-9	9-6	6-3	3-1
Inter isohyetal area (km^2)	92	128	120	175	85

Isohyetal	Avg value of P (cm)	Area (km^2)	(Avg P) x Area
15-12	13.5	92	1242
12-9	10.5	128	1344
9-6	7.5	120	900
6-3	4.5	175	787.5
3-1	2	85	170
		$\Sigma = 600$ km^2	$\Sigma = 4443.5$

$$\bar{P} = \frac{\Sigma\left(\frac{P_i + P_{i+1}}{2}\right) \times A_i}{\Sigma A_i} = \frac{4443.5}{600} = 7.4\text{cm}$$

Chapter:-4- Infiltration and percolation.

Definations:-

Infiltration is the flow of water into the ground through the soil surface. The distribution of soil moisture within the soil profile during infiltration process is illustrated in fig. When water is applied at the surface of soil, four moisture zone in the soil can be identified.

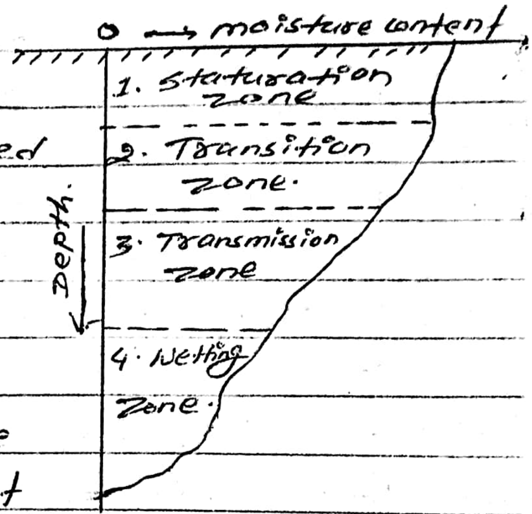


Fig:- Distribution of soil moisture.

Zone 1: At the top, a thin layer of saturated zone is created.

Zone 2: Beneath zone 1, there is transition zone.

Zone 3: Next zone is transmission where the down water motion of the moisture takes place. The moisture content in this zone is above field capacity but below saturation. Further it is characterized by unsaturated flow and fairly uniform moisture content.

Zone 4: The last zone is the wetting zone. The soil moisture in this zone will be at or near field capacity and the moisture content decreases with the depth. The boundary of the wetting zone is the wetting front where a sharp discountinuity exists between the newly wet soil and original moisture content of the soil.

Infiltration Capacity:-

The maximum rate at which a given soil at a given time can absorb water is defined as

the infiltration capacity. It is designated as f_p and is expresed in units of cm/h.

The actual rate of infiltration f can be expressed as

$f = f_p$ when $i \geq f_p$

and $f = i$ when $i < f_p$

Where i = intensity of rainfall.

The infiltration capacity of soil is high at the begining of a storm and has an expontial decay as time elapses. The typical variation of infiltration capacity f_p of a soil with time is shown in figure. The infiltration capacity of an area is dependent on a large number of factors, chief of them are

→ characteristics of soil surface.

→ Vegetative cover.

→ Soil temperature.

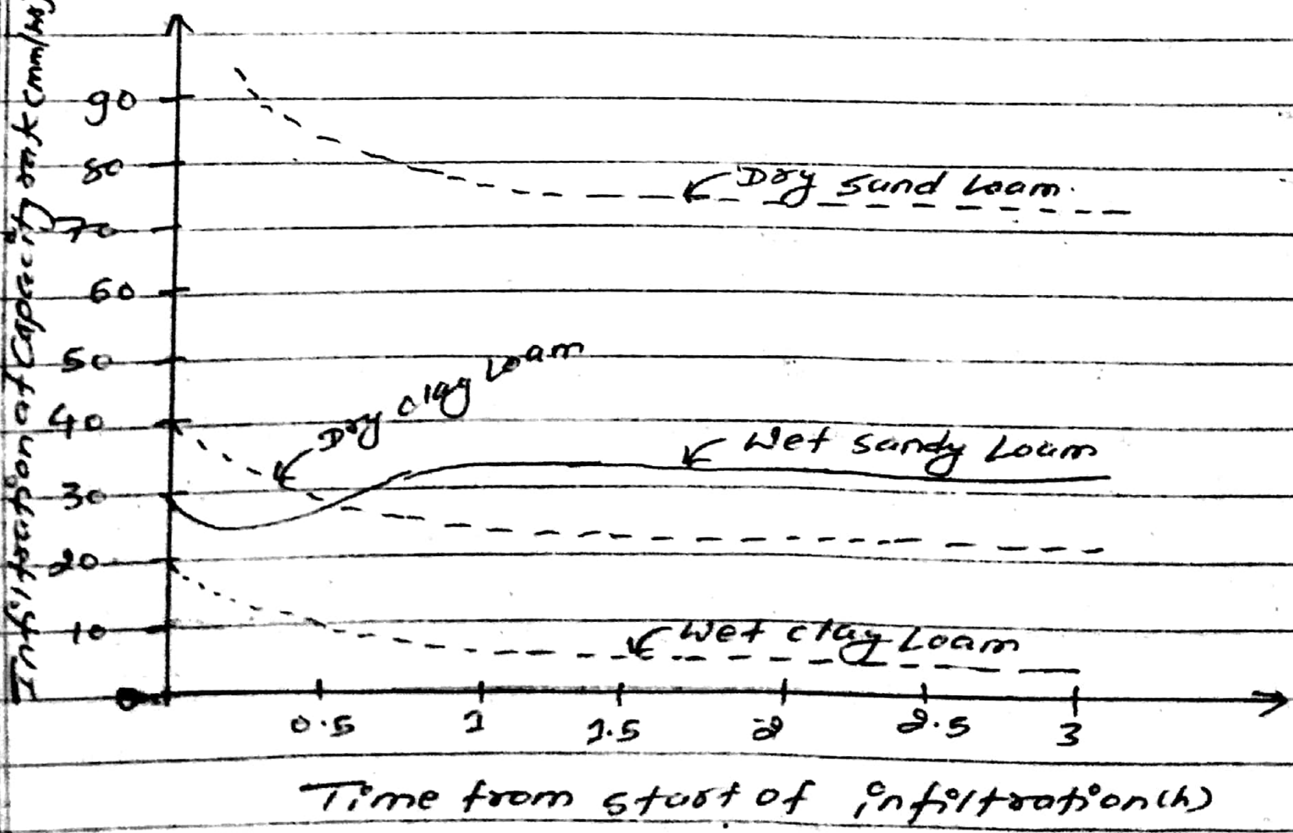


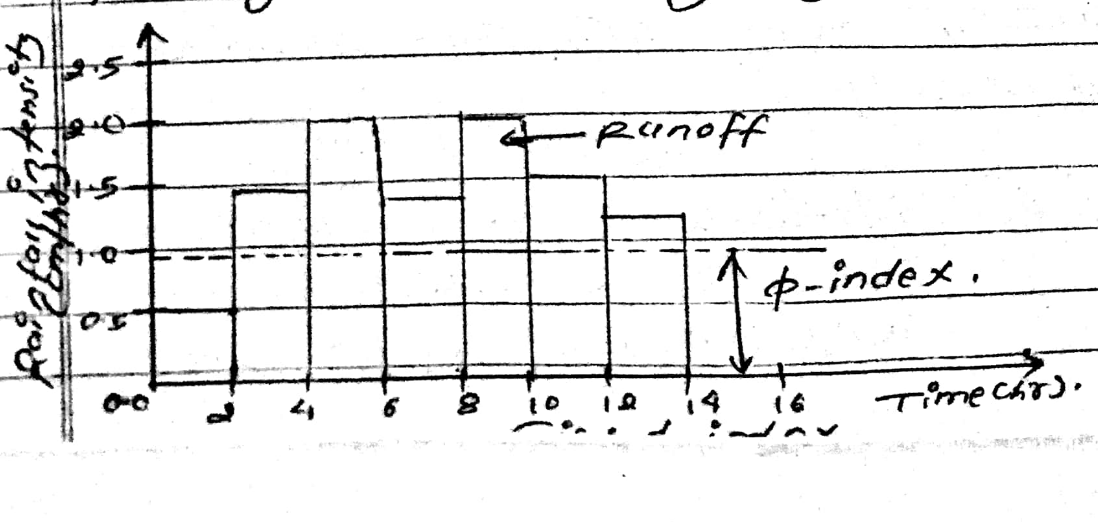
Fig:- Variation of infiltration capacity

Infiltration indices (ϕ and W)

In hydrological calculation involving floods it is found convient to use a constant value of infiltration rate for the duration of storm. The defined average infiltration rate is called infiltration index and two types of indies are in common use.

ϕ-Index :-

The ϕ-index is the average rainfall above which the rainfall volume is equal to runoff volume. The ϕ-index is derived from the rainfall hyetograph with the knowledge of resulting runoff volume. The initial loss is also considered as infiltration. The ϕ-index is found by treating it as a constant infiltration capacity. If the rainfall intensity is less than ϕ, then the infiltration rate is equal to rainfall intensity. However if the rainfall intensity is larger than ϕ the differences between the rainfall and infiltration in an interval of time represents the runoff volume. The amount of rainfall in excess of the index is called rainfall excess. The ϕ-index thus accounts for the total abstraction and enables magnitude to be estimated for a given rainfall hyetograph.



W-Index :-

In an attempt to refine the ϕ-index the initial losses are separated from the total abstractions and an average value of infiltration rate called W-index.

$$W = \frac{P - R - I_a}{t_e}$$

Where;

P = total storm precipitation (cm)

R = total storm runoff (cm)

I_a = Initial lossees (cm)

t_e = duration of rainfall excess, i.e, the total time in which the rainfall intensity is greater than W in hours and

W = defined average rate of infiltration (cm).

Since, I_a rates are difficult to obtained, the accurate estimation of W-index is rather difficult. The minimum value of W-index obtained under very wet soil condition, representing the constant minimum rate of infiltration of the catchment is known as W_{min}. It is to be noted that both the index i.e, ϕ & W-index vary from storm to storm.

Horton's Equation :-

Horton's Equation expresses the decay of infiltration capacity with time as an expontial decay given by;

$$f_p = f_c + (f_0 - f_c) \cdot e^{-K_h t} \quad \text{for } 0 \geq t \geq t_c$$

Where; f_p = infiltration capacity at any time t from start of rainfall.

f_0 = initial infiltration capacity at $t = 0$.

$t = t_c$ Also f_c is sometimes known as constant rate or ultimate infiltration capacity.
k_h = Horton's decay coefficent which depends upon soil characteristic and vegitation cover.

Infiltrometers :-

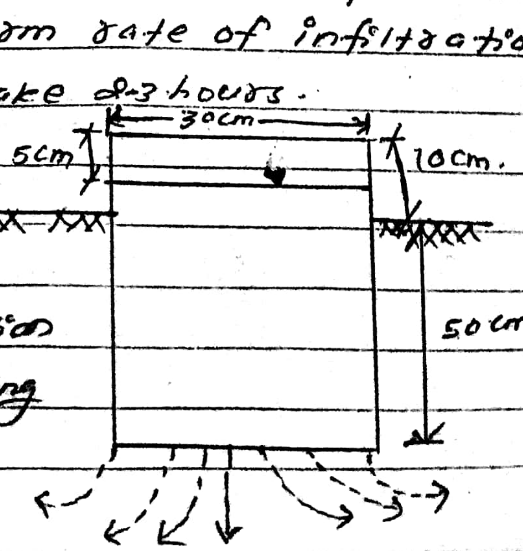
Two types of flooding type infiltrometers are in common use. They are;

1. Tube-type (or simple) infiltrometer.
2. Double ring infiltrometer.

1. Tube-type (or simple) infiltrometer :-

This is a simple instrument cosisting essentially a metal cylinder, 30cm diameter and 60cm long open at both end. The cylinder is driven into the ground to a depth of 50cm. Water is poured into top part upto depth of 5cm and a pointer is set to mark water level. As infiltration proceeds the volume is made by adding water from a burette to keep the water level at the tip of pointer. Knowing the volume of water added during the different time interval the plot of infiltration capacity Vs time is obtained. The experiments are contineued till a uniform rate of infiltration is obtained and this may take 2-3 hours.

The surface of the soil is usually protected by a perforated disc to prevent the formation of turbidity and its settling on soil surface.



(4)

2. Double-ring infiltrometer :-

This most commonly used infiltrometer is designed to overcome the basic objection of tube infiltrometer, viz. the tube area is not representative of infiltration area. In this two sets of concentrating ring with diameters of 30cm and 60cm and of a minimum length of 25 cm are used. The two ring are inserted into the ground and water is applied into both the ring to maintain a constant depth of about 5cm. The outerring provides water jacket to the infiltration water from the inner ring and hene prevents the spreading out of the infiltering water of inner ring. The water depths in the inner and outer rings are kept the same during the observation period. The measurement of the water volume is done on inner ring only. The experiment is carried ~~out~~ out till constant infiltration rate is obtained.

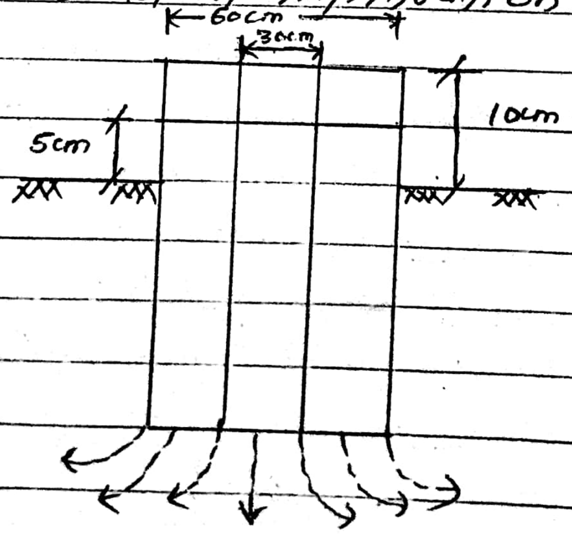


Fig:- Double ring infiltrometer.

K. Subramanya ppg-119-3.18

Numerical parts:-

The mass curve of an isolated storm in a 500 ha. Water is as follows. If the direct runoff produced by the storm is measured at the outlet of water-shed as 0.34 million m^3. Estimate the ϕ-index & duration of rainfall excess. Also plot a total rainfall runoff and ϕ-index in the graph.

t (hr)	0	2	4	6	8	10	12	14	16	18
cu.r.f. (cm)	-	0.8	2.6	2.8	4.1	7.3	10.8	11.8	12.4	12.6

Solution:-

$$\text{Runoff (R.O.)} = \frac{0.34 \times 10^6 m^3}{500 \times 10^4 m^2} = 0.068 m = 6.8 cm.$$

t (hr)	cu.r.f. (cm)	Incremental rainfall in each time interval ΔP (cm)	$i = \left(\frac{\Delta P}{\Delta t}\right) \left(\frac{cm}{hr}\right)$
0	-	-	
2	0.8	0.8	0.4
4	2.6	1.8	0.9
6	2.8	0.2	0.1
8	4.1	1.3	0.65
10	7.3	3.2	1.6
12	10.8	3.5	1.75
14	11.8	1.0	0.5
16	12.4	0.6	0.3
18	12.6	0.2	0.1

Total rainfall $= \Sigma \Delta P_i = \Sigma i * \Delta t$.

Where, ΔP = incremental rainfall in each time interval.

$i = \left(\frac{\Delta P}{\Delta t}\right)$ = rate of rainfall in each time interval.

Total duration of rainfall; $t = \Sigma \Delta t_i$

$$R.O. = \Sigma (i_i - f_i) * \Delta t.$$
$$= \Sigma (i_i - \phi) * \Delta t.$$

Trial 1

$\phi = \frac{\text{Amount of infiltration}}{\text{Time}} = \frac{P_e - Q}{t_e} = \frac{12.6 - 6.8}{18} = 0.322$ cm/hr.

Where, P_e is the amount of pptn during which runoff take.

Q is the amount of R.O & t is the effective time at which Runoff occurs.

Assumed the R.O. occurs from the beiging of the R.f. & hence $t_e = 18$ hr.

Check

$R.O. = \sum (i - \phi) * \Delta t$

$R.O. = [(0.4 - 0.322) + (0.9 - 0.322) + \cancel{(0.1 - 0.322)}^{0} + (0.65 - 0.322) + (1.6 - 0.322) + (1.75 - 0.322) + (0.5 - 0.322) + \cancel{(0.3 - 0.322)}^{0} + \cancel{(0.1 - 0.322)}^{0}] * 2.$

$R.O. = 7.736$ cm.

Trial 2

$\phi = \frac{P_e - Q}{t_e}$, Here, effective time at which R.O. occurs is ; $t_e = (18-6)$ hr. $= 12$ hr.

$\therefore \phi = \frac{(12.6 - 0.2 - 0.6 - 0.2) - 6.8}{12} = 0.4$ cm/hr.

Check.

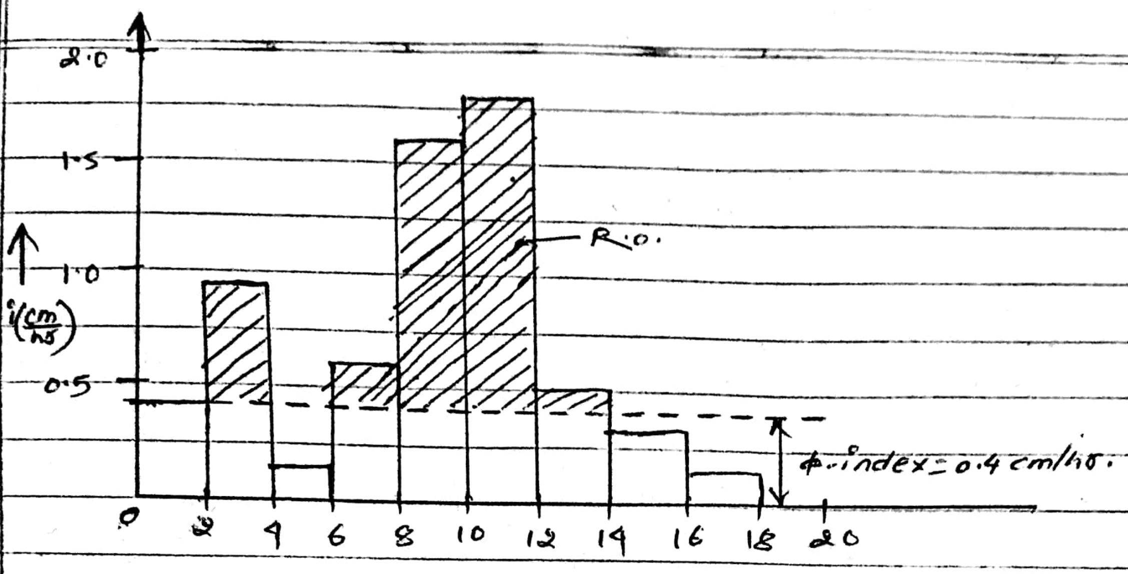
$R.O. = \sum (i - \phi) * \Delta t$

$R.O. = [\cancel{(0.4 - 0.4)}^{0} + (0.9 - 0.4) + \cancel{(0.1 - 0.4)}^{0} + (0.65 - 0.4) + (1.6 - 0.4) + (1.75 - 0.4) + \cancel{(0.5 - 0.4)} + \cancel{(0.3 - 0.4)}^{0} + \cancel{(0.1 - 0.4)}^{0}] * 2.$

$R.O. = 6.8$ cm.

Here, calculated R.O. is Equal to the given R.O. , so , the $\phi = 0.4$ cm/hr.

and Effective time $(t_e) = 10$ hr.



Subramanya Ex. 3.22.

An isolated 3-h storm carried over a basin in the following fashion.

% of catchment area	φ-index (cm/hr)	Rainfall (cm) 1st hour	2nd hour	3rd hour
20	1	0.8	2.3	1.5
30	0.75	0.7	2.1	1
50	0.50	1.0	2.5	0.8

Estimate the runoff from the catchment due to storm; hourly distribution of average rainfall and total rainfall on the catchment in this storm.

Solution:-

Average rainfall at time $t = \frac{\Sigma A_i \cdot \text{Rainfall}}{\Sigma A_i}$

Average rainfall in 1st hour $= \frac{0.2A \times 0.8}{A} + \frac{0.3A \times 0.7}{A} + \frac{0.5A \times 1}{A}$

$= 0.87$ cm.

Average rainfall in 2nd hour $= \frac{0.2A \times 2.3}{A} + \frac{0.3A \times 2.1}{A} + \frac{0.5A \times 2.5}{A}$

$= 2.34$ cm.

Average rainfall in 3rd hour $= \frac{0.2A \times 1.5}{A} + \frac{0.3A \times 1}{A} + \frac{0.5A \times 0.8}{A}$

$= 1$ cm.

Hence, hourly distribution of rainfall in 3 hrs = 0.87 cm, 2.34 cm and 1 cm.

Total rainfall = 4.21 cm.

$$\text{Total runoff} = \frac{\sum A_i * (\text{Rainfall} - \phi\Delta t)}{\sum A_i}$$

$$= \frac{0.2A}{A}[0+(2.3-1)+(1.5-1)] + \frac{0.3A}{A}[0+(2.1-0.75)+(1-0.75)] +$$

$$\frac{0.5A}{A}[(1-0.50)+(2.5-0.50)+(0.8-0.50)]$$

$$= 0.36 + 0.48 + 1.4$$

$$= 2.27\,cm. \quad \underline{\text{Ans}}$$

K. Subramanya Ex. 3.20

In a 140-min storm the following rates of rainfall were observed in successive 20 min intervals: 6, 6, 18, 13, 2, 2 and 12 mm/hr. Assuming the ϕ-index value as 3.0 mm/hr and a initial loss of 0.8 mm, determine the total rainfall, net runoff, and W-index for the storm.

Solution:-

Total rainfall $= \sum i_i * \Delta t$.

$$\text{Total rainfall} = \frac{6\times20}{60} + \frac{6\times20}{60} + \frac{18\times20}{60} + \frac{13\times20}{60} + \frac{2\times20}{60} + \frac{12\times20}{60}$$

$$= 19.667\,mm.$$

$$\text{Net runoff} = \sum(\text{Rainfall intensity} - \phi)\Delta t$$

$$= (6-3)\frac{\times20}{60} + (6-3)\frac{\times20}{60} + (18-3)\frac{\times20}{60} + (13-3)\frac{\times20}{60} + (12-3)\frac{\times20}{60}$$

$$= 13.33\,mm$$

Initial Loss = 0.8 mm

i.e. Effective duration (t_e) = 100/60 = 1.667 hrs.

$$P = 19.667 - 2\times\frac{20}{60} - 2\times\frac{20}{60} = 18.33$$

$$W\text{-index} = \frac{P - q - I_a}{t_e} = \frac{(18.397 - 13.33 - 0.8)}{1.667} = 2.52\,mm/hr$$

Ans

K. Subramanya Ex. 3.8

The infiltration capacity in a basin is represented by Horton's Equation as, $f_p = 3.0 + e^{-2t}$, Where f_p is is cm/hr. and t is in hours. Assuming the infiltration to take place at capacity rates in a storm of 60 minutes duration, estimate the depth of infiltration in (i) the first 30 minutes and (ii) the second 30 minutes of the storm.

Solution:-

$$F_p = \int_0^t f_p\,dt \quad \text{and} \quad f_p = 3.0 + e^{-2t}.$$

(i) In the first 0.5 hours

$$F_{p_1} = \int_0^{0.5} (3.0 + e^{-2t})\,dt = \left[3.0t - \frac{1}{2}e^{-2t}\right]_0^{0.5}$$

$$= \left[(3.0 \times 0.5) - (\tfrac{1}{2})(e^{-(2\times 0.5)})\right] - \left[-\tfrac{1}{2}\right] = (1.5 - 0.184) + 0.5$$

$$= 1.816\,cm.$$

(ii) In the second 0.5 hour.

$$F_{p_2} = \int_{0.50}^{1.0} (3.0 + e^{-2t})\,dt = \left[3.0t - \frac{1}{2}e^{-2t}\right]_{0.5}^{1.0} = 1.616\,cm.$$

Ans.

K. Subramanya Ex. 3.9

The infiltration capacity of soil in a small watershed was found to be 6 cm/hr. before a rainfall event. It was found to be 1.2 cm/hr. at the end of 8 hours of storm. If the total infiltration during the 8 hour period of storm was 15 cm, estimate the value of the decay coefficient k_h in Horton's infiltration capacity equation.

Solution:-

Horton's equation is $f_p = f_c + (f_0 - f_c)\cdot e^{-k_h t}$.

and; $$F_p = \int_0^t f_p(t)\,dt = f_c t + (f_0 - f_c)\int_0^t e^{-k_h t}\,dt.$$

As; $t \to \infty$, $\int_0^{\infty} e^{-k_h t}\,dt \to \frac{1}{k_h}$. Hence for a large value of t.

$$F_p = f_c t + \frac{(f_o - f_c)}{K_h}$$

Here; $F_p = 15.0\,cm$, $f_o = 6.0\,cm/hr$, $f_c = 1.2\,cm/hr$ and $t = 8$ hours.

$$15.0 = (1.2 \times 8) + (6.0 - 1.2) / K_h$$

$$K_h = 4.8 / 5.4 = 0.888\,h^{-1}.$$

Ans.

HM Raghunath pg.98 - Ex.14

An infiltration capacity curve prepared for a catchment indicated at an initial infiltration capacity of 2.5 cm/hr. an attains constant values of 0.5 cm/hr. after 10 hr. of rainfall with the horton's constant $K = 6\,day^{-1}$. determine the total infiltration loss.

Solution:-

$f_o = 2.5\,cm/hr.$ $f_c = 0.5\,cm/hr.$ $K = 6\,day^{-1} = 0.24\,hr^{-1}$

We know that;

$$f_p = f_c + (f_o - f_c) \cdot e^{-Kt}.$$

Now, total amount of infiltration loss; $F_p = \int_0^t f_p * dt$.

$$= \int_0^{10} [0.5 + (2.5 - 0.5) \cdot e^{-0.24t}]\,dt = 13.66\,cm.$$ Ans.

HM Raghunath pg.93 - Q.15

Determine the Runoff from a catchment of area $1.8\,km^2$ over which 8 cm of rainfall over during one day storm and infiltration capacity curve prepared indicated an initial infiltration capacity of 10 mm/hr. & attain a constant value of 3 mm/hr. after a 16 hr. of rainfall with the horton's constant $K = 5\,hr^{-1}$ a floating pan installed in the catchment indicated a decrease of 6 mm in water level of that day.

Solution:-

Area of catachment $= 1.8\,km^2$.

Total rainfall. $(P) = 8\,cm$ (in 24 hour duration i,e, $t = 24\,hr$.)

$f_0 = 10 mm/hr$, $f_c = 3 mm/hr$; $k = 5 hr^{-1}$

Evaporation loss (E_p) = 6mm

We know that;

Runoff = precipitation − Infiltration − Evaporation loss

= 8 − Infiltration − Evaporation Loss.

∴ Total amount of Infiltration (F_p) = $\int_0^{24} (3 + 7e^{-5t})\, dt$

= 7.34 cm.

Evaporation Loss (E_L) = $C_p \times E_p$

Where, C_p is pan coefficient and assumed 0.7

∴ $E_L = 0.7 \times 6$ mm = 4.2 mm = 0.42 cm.

∴ Runoff = (8 − 7.34 − 0.42) cm = 0.24 cm.

Now volume of R.O. from catchment = A × depth of runoff.

$= (1.8 \times 10^6 \times 0.24 \times 10^{-2})\ m^3$

Ans

Chapter :-5 :- Evaporation and Evapotranspiration

Definations :-

Evaporation is the process in which a Liquid changes to the gaseous state at the free surface, below the boiling point through the transfer of heat energy. Evaporation is a colling process in that latent heat of vaporization (at about 585 cal/g of evaporated Water) must be provided by the water body.

meterological parameters :-

The Evaporation process depends upon the following parameters.

1. Vapour pressure :-

The rate of Evaporation is proportional to the difference between saturation vapour pressure at the Water temperature, e_w and the actual vapour pressure in the air, e_a. Thus,

$$E_L = C(e_w - e_a) \quad \text{--- (1)}$$

Where, E_L = rate of Evaporation (mm/day)
and C = constant

e_w and e_a are in mm of Hg (mercury), Equation (1) is known as Dalton's law of evaporation.
Evaporation continues till $e_w = e_a$. If $e_w > e_a$ condensation takes place.

2. Temperature :-

The rate of evaporation increases with increases in water temperature. Regarding air temperature, although there is a general increase in evaporation rate with increasing temperature, a high correlation

between evaporation rate and air temperature doesnot exist. Thus for the same mean monthly temperature it is possible to have evaporation to different degrees in lake in different month.

3. Wind :-

Wind help in removing the evaporated water from the zone of evaporation and consequently creates greater scope for evaporation. However, if the wind velocity is large enough to remove all the evaporated water vapour, any further increase in wind velocity doesnot influence the evaporation. Thus the rate of evaporation increases with the wind speed up to critical speed beyond which any further increases in the wind speed has no influence on evaporation rate.

4. Radiation :-

Radiation is the means of transfer of energy by a source to another body by a means of Electromagnetic waves. Sun being the major source of energy transmits radiation known as solar radiation. Solar radiation acts as the fuel for hydrologic cycle. Solar radiation controls weather and climate of earth. The solar radiation is usually measured in cal/m² minutes.

5. Humidity :-

Amount of water vapour present in air is known as humidity. humidity is closely related to the temperature. As the temperature increases, the capacity of the air to retain the water vapour increases. Because of this reason as the temperature increases the saturation vapour pressure also increases.

Evaporimeters :-

Evaporimeters are water-containg pans which are exposed to atmosphere and loss of water by evaporation measured in them at regular intervals. Metrological data, such as humidity, wind movement, air and water temperature and precipitation are also noted along with evaporation measurements.

Types of Evaporimeters :-

1. Class A Evaporation pan :-

It is a standard pan of 1210 mm and 255 mm depth used by US Weather Bureau and is known as class A Land pan. The depth of water is maintained between 18 cm and 20cm. The pan is normally made of unpainted galvanised iron sheet. The pan is placed on a wooden platform of 15cm height above the ground to allow free circulation of air below pan.

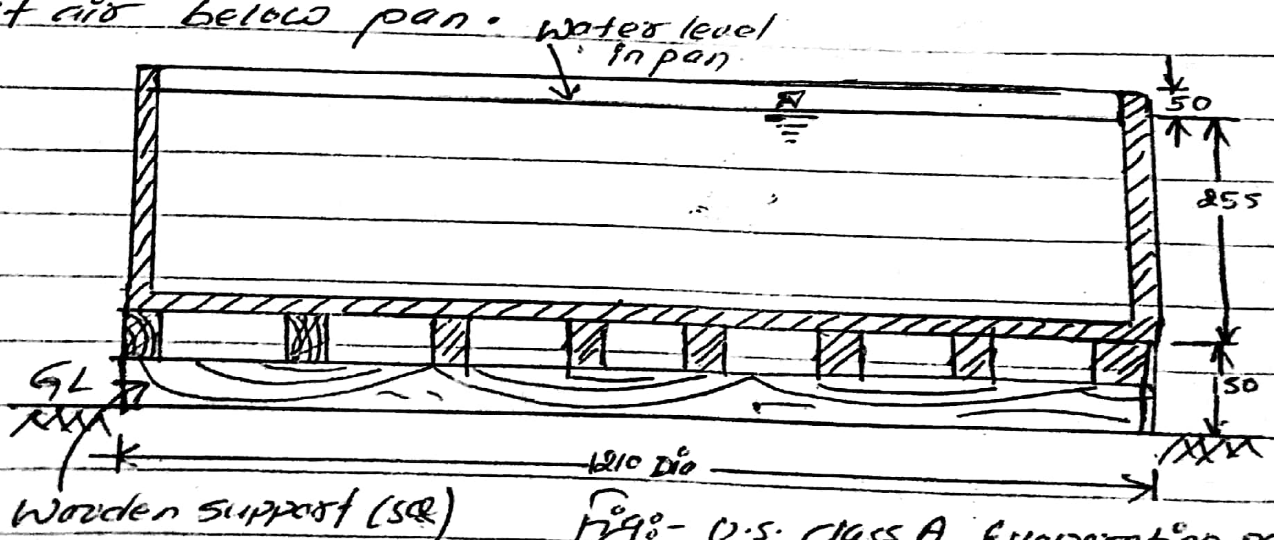


Fig:- U.S. Class A Evaporation pan.

2. ISI standard pan :-

This pan is also known as modified ~~pan~~ class A pan consists of a pan 1220mm in diameter with 255 mm of depth. This pan is made up of copper sheet of 0.9mm thickness, tinned inside and painted white

outside. A calibrated cylindrical measure is used to add or remove water maintaining the water level in the pan to fixed mark. The top of the pan is covered fully with hexagonal wire netting of galvanized iron to protect the water in the pan from birds. The evaporation from this pan is found to be less by about 14% compared to that from unscreened pan. The pan is placed over a square wooden platform of 1225 mm width and 100 mm height to enable circulation of air underneath the pan.

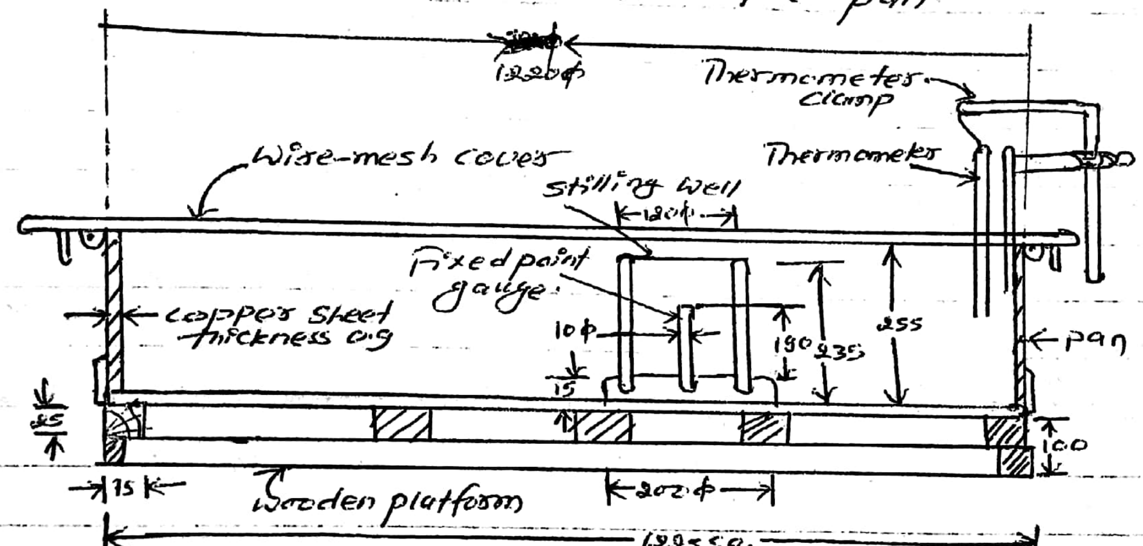


Fig:- ISI Evaporation pan

3. Colorado sunken pan:-

This pan is 920 mm square and 460 mm deep in made up of unpainted galvanised iron sheet and buried into the ground within 100 mm of the top.

The chief advantage of sunken pan is that radiation and aerodynamics characteristics are ~~those of~~ similar to those of a lake.

Disadvantage

→ Difficult to detects leaks.

→ expensive to install.

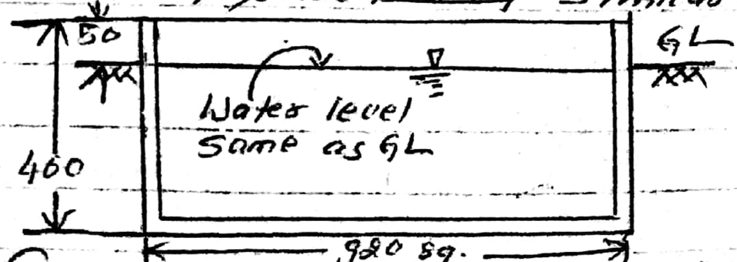


Fig:- Colorado sunken Evaporation pan

Imp **Pan coefficent C_p :-**

The Evaporation observed from a pan has to corrected to get the evaporation from a lake under a similar climatic and exposure conditions. Thus a coefficient is introduced as

$$\boxed{\text{Lake evaporation} = C_p \times \text{pan evaporation}}$$

in which C_p = pan coefficient. the values of C_p in use for different pan are given as,

Types of pan	Average Value	Range
Class A Land pan	0.70	0.60 - 0.80
ISI pan (modified class A)	0.80	0.65 - 1.10
Colorado Sunken pan	0.78	0.75 - 0.86
USGS floating pan	0.80	0.70 - 0.82

Imp **Methods to Reduced Evaporation Losses :-**

Various methods available for reduction of Evaporation losses can be considered in three Categories.

1. Reduction of Surface area :-

Since the Volume of Water lost by evaporation is directly proportional to the Surface area of the water body, the reduction of the surface area Whereever feasible reduces evaporation Losses. measure Like having deep reservoir in place of Wider one and Elimination of shallow areas can be considered under this category.

2. mechanical Covers :-

permanent roofs over the reservoir, temporary roofs and floating roofs such as rafts and Light-Weight floating particles can be adopted Wherever

feasible. obviously these measures are limited to very small water bodies such as ponds, etc.

3. Chemical Films:-

This method consists of applying a thin chemical film on the water surface to reduce evaporation. Currently this only feasible method available for reduction of evaporation of reservoirs up to moderate size.

→ Certain chemical such as cetyl alcohol (hexadecanol) and stearyl alcohol (octadecanol) form monomolecular layer on a water surface. these layer act as evaporation inhibitors by preventing the water molecules to escape past them.

Imp. Analytical methods of Evaporation Estimation:-

The analytical methods ~~of~~ for the determination of Lake evaporation can be broadly classified into three categories as;

1. Water-budget method 2. Energy-balance method
3. mass-transfer method.

1. Water-budget method:-

It involves writing the hydrological continuity equation for the lake and determing the evaporation from a knowledge or estimation of other variables. Thus considering the daily average values for a lake, the continuity equation is written as;

$$P + V_{is} + V_{ig} = V_{os} + V_{og} + E_L + \Delta S + T_L \quad \text{—} (1)$$

Where;

p = daily precipitation.

V_{is} = daily surface inflow into the Lake.
V_{ig} = daily ground water inflow.
V_{os} = daily surface outflow from the Lake.
V_{og} = daily seepage outflow.
E_L = daily Lake evaporation
ΔS = increase in lake storage in a day
T_L = daily transpiration Loss.
Equation (1) can be written as;

$$E_L = P + (V_{is} - V_{os}) + (V_{ig} - V_{og}) - T_L - \Delta S \quad \text{---} (11)$$

In this the terms P, V_{is}, V_{os} and ΔS can be measured. However, it is not possible to measure V_{ig}, V_{og} and T_L and therefore these quantities can ~~be~~ only be estimated.

2. Energy-Budget method :-

The energy-budget method is an application of the Law of conservation of energy. The energy available for evaporation is determined by considering the incoming energy, outcoming energy and energy stored in the water body over a known time interval.

Considering the water body as in fig., the energy balance to evaporating surface in a period of one day is given by;

$$H_n = H_a + H_e + H_g + H_s + H_i$$

Where; H_n = net heat energy received by the water surface.

$= H_c(1-r) - H_b$

in which $H_c(1-\gamma)$ = incoming solar radiation into a Surface of reflection coefficient (albedo) γ.

H_b = back radiation (long wave) from water body.

H_a = Sensible heat transfer from water surface to air.

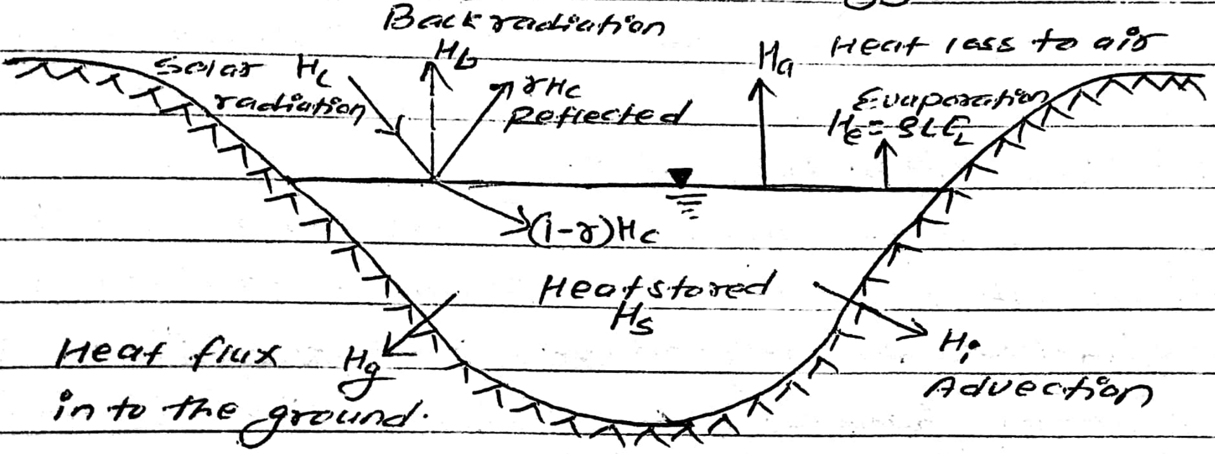
H_e = heat energy used up in evaporation.

= $\rho L E_L$, where ρ = density of water, L = Latent heat of evaporation and E_L = evaporation in mm.

H_g = heat flux in to the ground.

H_s = heat stored in water body.

H_i = net heat conducted out of the system by water flow. (advected energy).



The sensible heat term 'H_a' which cannot be directly measured is estimated using Isowen's ratio β given by expression.

$$\beta = \frac{H_a}{\rho L E_L} = 6.1 \times 10^{-4} \times P_a \frac{T_w - T_a}{e_w - e_a}.$$

Where, P_a = atmospheric pressure in mm of Hg.

e_w = Saturated Vapour pressure in mm of Hg.

e_a = actual vapour pressure of air in mm of Hg.

T_w = Temperature of water surface in °c

T_a = temperature in air in °c

The term E_L is calculated as;

$$\boxed{E_L = \frac{H_n - H_g - H_s - H_i}{\rho L (1+\beta)}}$$

This method has been found to give satisfactory results with errors of the order of 5% when applied to period less than a weak.

3. Mass-Transfer method :-

This method is based on theories of turbulent mass transfer in a boundary layer to calculate the mass water vapour transfer from the surface to the surrounding atmosphere.

Evapotranspiration :-

While transpiration takes place, the land area in which plants ~~area~~ stand also lose moisture by the evaporation ~~d~~ of water from soil and water bodies. It is found that evaporation and transpiriation processes can be considered adventageously under one head as evapotranspiration.

potential Evapotranspiration (penman's equation)

If the sufficient moisture is always avialable to completely meet the needs of vegetation fully covering the area, the resulting evapotranspiration is called potential evapotranspiration.

Penman's Equations :-

Imp

penman's equation is based on sound ~~[illegible]~~ theoritical reasoning and is obtained by a combination of the energy balance and

mass-transfer approach.

$$PET = \frac{AH_n + E_a \gamma}{A + \gamma}$$

where, PET = daily potential evapotranspiration in mm per day.

A = Slope of saturation vapour pressure Vs tempreature curve at the mean air tempreature, in mm of mercury per °c.

H_n = net radiation ~~of~~ in mm of evaporable water per day.

E_a = parameter including wind velocity and saturation deficit.

γ = phychrometric constant = 0.49 mm of mercury / °c.

The net radiation is same as used in energy budget and is estimated by following equation.

$$H_n = H_a(1-r)\left(a + \frac{bn}{N}\right) - \sigma T_a^4 \left(0.56 - 0.092\sqrt{e_a}\right)\left(0.10 + 0.90\frac{n}{N}\right).$$

H_a = incident solar radiation outside the atmosphere on a horizontal surface, expressed in mm of evaporable water per day.

a = a constant depending upon the latitude ϕ and is given by $a = 0.29\cos\phi$.

b = a constant with average value of 0.52.

n = actual duration of bright sunshine in hours.

N = maximum possible hour of bright sunshine.

r = reflection coefficient (albedo) for water r = 0.05.

σ = stefan-Boltzman constant = 2.01×10^{-9} mm/day.

T_a = mean air temperature in degree kelvin = 273 + °c.

• e_a = actual mean Vapour pressure in the air in mm of mercury.

The parameter E_a is estimated as

$$E_a = 0.35\left[1+\frac{U_2}{100}\right](e_w - e_a).$$

in which

U_2 = mean wind speed and 2m above ground is km/day.

e_w = Saturation Vapour pressure at mean air temperature in mm of mercury.

e_a = actual Vapour pressure, defined earlier.

Actual Evapotranspiration :-

Actual evapotranspiration is the quantity of water that is actually removed from the surface due to the process of evaporation and transpiration.

measurement of Evapotranspiration :-

The measurement of Evapotranspiration for a given vegetation type can be carried out in two ways; either by using lysimeters or by the use of field plots.

1. Lysimeters :-

A Lysimeters is a special watertight tank containing a block of soil and set in the field of growing plants. the plants grown in the lysimeters are the same as in the surrounding field. Evapotranspiration is estimated in terms of the amount of water

required to maintain constant moisture condition within the tank measured either volumetrically or gravimetrically through an arrangement made in the lysimeter. Lysimeter should be designed to accurately reproduce the soil conditions, moisture content, type and size of vegetation of the surrounding area. They should be so buried that the soil is at the same level inside and outside the container. Lysimeter studies are time-consuming and expansive.

2. Field-plots :-

In special plots all the elements of water budget in a known interval of time are measured and the evapotranspiration determined as;

Evapotranspiration = [precipitation + irrigation input − runoff − increase in soil storage groundwater loss]

Factors Affecting Evapotranspiration :-

The following factors affect the evapotranspiration

1. Climatological factors like percentage sunshine hours, wind speed, mean monthly temperature and humidity.

2. Crop factors like the type of crop and the percentage growing season.

3. The moisture level in the soil.

k. subramanya

Ex. 8.1

Numerical parts :-

Calculate the evaporation rate from an open water source if the net radiation is 250 W/m² and the air temperature is 30°c. Assume value of for sensible heat, ground heat flux heat stored in water body and advected energy is zero. The density of water at 30°c = 996 kg/m³.

Solution :-

Temperature $(T) = 30°c$.

Density of water $(\rho) = 996\ kg/m^3$.

Net radiation $(H_n) = 250\ w/m^2$.

Sensible Heat $(H_a) = 0$.

Ground heat flux $(H_g) = 0$

Heat stored in body $(H_s) = 0$.

Advected energy $(H_i) = 0$.

For $H_a = 0$.

Bowen's ratio $(\beta) = \frac{H_a}{\rho L E_L} = 0$ as $H_a = 0$.

Latent heat of vaporization $= 2501 - 2.37T$.

$= 2501 - 2.37 * 30\ kJ/kg$

$= 2429.9\ kJ/kg$

$= 2429900\ J/kg$.

Using Energy budget Formula;

$$E = \frac{H_n - H_g - H_s - H_i}{\rho L(1+\beta)}$$

$$= \frac{250-0-0-0}{996 \times 2429900}$$

$= 1.033 \times 10^{-7}\ m/s = 1.033 \times 10^{-7} \times 1000 \times 60 \times 60 \times 24$

$= 8.92\ mm/day$.

Tikaram Pokharel pg.no.60

An Evaporation pan of 1.4m diameter was used to find out evaporation loss from the reservoir. The pan was initially filled up with water up to a depth of 10cm. During the period of observation 2.5cm of rainfall was recorded. At the end of observation the depth of the water in the pan was found to be 9cm. Taking pan coefficient = 0.7, determine the volume of water evaporated from the reservoir. Take water spread of reservoir = 30 km^2.

Solution :-

Diameter of pan (d) = 1.4m.

Area of pan $(A_p) = \frac{\pi}{4} \times 1.4^2 = 1.539 m^2$.

Initial water level (I) = 10cm.

precipitation (P) = 2.5cm

final water level (O) = 9cm

$\therefore$ Evaporation $E = I + P - O$

$= 10 + 2.5 - 9$

$= 3.5 cm = 0.035 m$

pan coefficient (k) = 0.7.

Water spread area (A) = 30 km^2.

Let us take time = t hrs.

Rate of evaporation $(E_r) = \frac{E}{A_p \times t} = \frac{0.035}{1.539 * t}$

$= \left[\frac{0.0227}{t}\right]$ in m/m^2/h.

Evaporation from reservoir $= k \cdot E_r \cdot A \cdot t$.

$= 0.7 * \left[\frac{0.0227}{t}\right] * 30 * 10^6 * t$.

$= 476700 m^3$.

Ans

K. Subramanya Example 3.4

Estimate the PET of an area for the Season November to February in which Wheat is grown. The area is in North India at a Latitude of 30°N With mean monthly temperature as below.

month	Nov.	Dec.	Jan.	Feb.
Temp(°C)	16.5	13.0	11.0	14.5

Use the Blaney-criddle formula;

Solution :-

From the table;

For Wheat $k = 0.65$, Values of P_h for 30°N is read from the table, the temperature are Converted to Fahrenheit and the calculation are performed in the following table.

month	$\bar{T}_f$	P_h	$P_h \bar{T}_f / 100$
Nov.	61.7	7.19	4.44
Dec.	55.4	7.15	3.96
Jan.	51.8	7.30	3.78
Feb.	58.1	7.03	4.08
			$\Sigma P_h \bar{T}_f / 100 = 16.26$

From Blaney-criddle formula;

$$E_T = 2.54 K \cdot \left[\Sigma P_h \bar{T}_f / 100\right] = 2.54 \times 16.25 \times 0.65 = 26.85 \text{ cm.}$$

[Note :- Values of k for selected crops;

Crop	Average value	Range of monthly values
Rice	1.10	0.85 – 1.30
Wheat	0.65	0.50 – 0.75
maize	0.65	0.50 – 0.80
Sugarcane	0.90	0.75 – 1.00
Cotton	0.65	0.50 – 0.90
potatoes	0.70	0.65 – 0.75 .

]

K. Subramanya Example 3.2

Calculate the potential evapotranspiration from an area near New Delhi in the month of November by penman's formula Latitude: 28.4' N.
Elevation: 230m (above sea level)
mean monthly temperature: 19°c
mean relative humidity: 75 %
mean observed Sunshine hours: 9h.
Wind Velocity at 2m height: 85 km/day.
Nature of surface cover: close ground-green crop.

Solution:-

From Table 3.3 of K. Subramanya, we have
$A = 1.00$ mm/°c , $e_w = 16.05$ mm of Hg.
From Table 3.4;
$H_a = 9.506$ mm of Water/day.
from Table 3.5
$N = 10.716$ hr. $\frac{n}{N} = \frac{9 \text{ hr}}{10.716} = 0.84$.
From given data;
$e_a = R.H \times e_w = 0.75 \times 16.50 = 12.38$ mm of Hg.
$a = 0.29 \cos\phi = 0.29 \cos 28°4' = 0.2559$.
$b = 0.52$
$\sigma = 2.01 \times 10^{-9}$ mm/day.
$T_a = (273+19)k = 292k$.
$\sigma T_a^4 = 14.613$
r = albedo for closed ground green crop is taken as 0.25
We know;

$$PET = \frac{AH_n + E_a \gamma}{A + \gamma}.$$

$$H_n = 9.506 \times (1-r)\left(a + b\frac{n}{N}\right) - \sigma T_a^4 (0.56 - 0.092\sqrt{e_a}) \times \left(0.10 + 0.90\frac{n}{N}\right)$$

$= 9.506 \times (1-0.25) \times (0.2559 + 0.52 \times 0.84) - 14.163 (0.56 - 0.092\sqrt{12.38})$

$\times (0.10 + 0.90 \times 0.84)$

$= 1.990$ mm of water/day.

$E_a = 0.35 \left[1 + \frac{U_2}{160}\right](e_w - e_a)$

$= 0.35 \left[1 + \frac{85}{160}\right](16.50 - 12.38]$

$= 2.208$ mm/day.

We know, $\gamma = 0.49$ mm of mercury/°C

$\therefore$ PET $= \frac{(1 \times 1.990) + (2.208 \times 0.49)}{(1 + 0.49)}$

$= 2.06$ mm/day.

K subramanya Examples 3.3

Using the data of above questions; estimate the daily evaporation from a lake situated in that place.

Solutions:-

For estimating the daily evaporation from a lake, penman's Equation is used with the albedo $r = 0.05$.

Hene;

$H_n = H_a (1-r)\left(a + b\frac{n}{N}\right) - \sigma T_a^4 (0.56 - 0.092\sqrt{e_a}) \times \left(0.10 + 0.90\frac{n}{N}\right)$

$H_n = 8.506(1 - 0.05)(0.2559 + 0.52 \times 0.84) - 14.613 (0.56 - \sqrt{12.38}) \times (0.10 + 0.90 \times 0.84)$

$H_n = 3.306$ mm of water/day.

$E_a = 2.208$ mm/day.

$\therefore$ PET = Lake evaporation

$= \frac{(1.0 \times 3.306) + (2.208 + 0.49)}{(1.0 - 0.49)}$

$= 2.95$ mm/day.

Tikaram pokhrel
Exam questions

Estimate daily evaporation from a lake at 30°N for april by penman method with the following mean monthly data.

Ta, Kelvin	RH %	n, hrs	U_2 m/s	Ha, mm/day	N hrs
293	65	10	1.2	148	12.9

Solution:-

We know, $PET = \dfrac{AH_n + E_a \gamma}{A+\gamma}$

$H_n = H_a(1-r)\left(a + \dfrac{bn}{N}\right) - \sigma T_a^4 (0.56 - 0.092\sqrt{e_a})\left(0.10 + 0.90\dfrac{n}{N}\right)$.

$E_a = 0.35\left[1 + \dfrac{U_2}{1021}\right](e_w - e_a)$

Let us assume $A = 1 mm/°c$.

$\therefore e_w = 4.584 \exp\left[\dfrac{17.27t}{237.3+t}\right]$ mm of Hg where t- temperature in °C

$= 4.584 \exp\left[\dfrac{17.27 \times 20}{237.3+20}\right]$ mm of Hg

$= 17.548$ mm of Hg.

$e_a = e_w * RH = 17.548 \times 0.65$ mm of Hg $= 11.406$ mm of Hg.

$\therefore a = 0.29\cos\phi$

$= 0.29\cos 30° = 0.251$

$b = 0.52$

$\sigma = 2.01 \times 10^{-9}$ mm/day.

$T_a = 293K$

$\gamma = 0.05$

$\dfrac{n}{N} = \dfrac{10}{12.9} = 0.775.$

$H_a = 14.8$ mm of water/day.

$\therefore H_n = 14.8 \times (1-0.05)(0.251 + 0.52 \times 0.775) - 2.01 \times 10^{-9} \times 293^4(0.56 - 0.092\sqrt{11.46}) \times (0.10 + 0.90 \times 0.775)$

$= 11.720$ mm of water/day.

$$E_a = 0.35 \times \left[1 + \frac{u_2}{160}\right](e_w - e_a)$$

$u_2 = 1.2\ m/s = \frac{1.2}{1000} \times 24 \times 60 \times 60\ km/day = 103.68\ km/day.$

$$\therefore E_a = 0.35 \times \left[1 + \frac{103.68}{160}\right](17.548 - 11.406)$$

$= 3.542\ mm/day.$

$\gamma = 0.49$

$$\therefore PET = \frac{(1 \times 11.720) + (3.542 \times 0.49)}{(1+0.49)}$$

$= 9.03\ mm/day.$ Ans.

[Note :- Usual ranges of Value of γ are given below

Surface	Range of γ values
Closed ground crops	0.15 - 0.25
Bare lands	0.05 - 0.45
Water Surface	0.05
Snow	0.45 - 0.95.

]

K.Subramanya problems 3.2

A class A pan was set up adjacent to Lake. The depth of water in the pan at the beining of certain week was 195mm. In that week there was a rainfall of 45mm and 15mm of water was removed from pan to keep the water level within the specified depth range. If the depth of water in the pan at the end of week was 190mm. Calculate the pan evaporation. using a suitable pan coefficient estimate the lake evaporation in that week.

Solution :-

Initial Water Level (I) = 195 mm.

precipitation $(P) = 45mm$
Removed Water $= 15mm$
Final Water Level $(O) = 190mm$
pan Evaporation $(E_L) = ?$
pan Evaporation $(E_L) = I + P - O -$ Removed Water.
$= (195 + 45 - 15 - 190)mm$
$= 35mm.$
For a A class pan, pan coefficient $= 0.7$
$\therefore$ Lake evaporation = pan coefficient $\times$ pan Evaporation
$= 0.7 \times 35 = 24.5\ mm$ Ans

K. subramanya problems 3.6

A reservoir had an average surface area of $20km^2$ during June 1882. In that month the mean rate of inflow $= 10m^3/s$, outflow $= 15m^3/s$, monthly rainfall $= 10cm$ and change in storage $= 16$ million m^3. Assuming the seepage losses to be $1.8cm$, estimate the Evaporation in that month.

Solution

Average surface area $= 20km^2 = 20 \times 10^6 m^2$.
mean rate of inflow $= 10m^3/s$
Total inflow in one month $(I) = \frac{10}{20 \times 10^6} \times 30 \times 24 \times 60 \times 60 m$
$= 1.296m = 129.6cm.$

monthly precipitation $(P) = 10cm.$
outflow rate $= 15m^3/s$
Total outflow in one month $= \frac{15}{20 \times 106} \times 30 \times 24 \times 60 \times 60$
$= 1.944m = 194.4cm$

Change in storage $(\Delta S) = 16$ million $m^3 = \frac{16 \times 10^6}{20 \times 10^6} m = 0.8m = 80cm$
Seepage Loss $(L_{se}) = 1.8cm.$
Now, $E_L = I + P + \Delta S - O - L_{se} = (129.6 + 10 + 80 - 194.4 - 1.8)cm$
$= 23.4\ cm$
Ans

Chapter :- 6 :- Runoff and stream Flow.

Defination :-

Runoff is defined as excessive rainfall which flow from the ground Surface, subsurface and groundwater flow to the stream is called runoff.

Imp **Components of Runoff :-**

→ Surface runoff / overland flow.
→ Subsurface runoff / Inter flow.
→ Groundwater flow / base flow.

Direct runoff.

Total runoff flow of the area = (Surface flow + Interflow) + (Groundwater flow.)

Base flow.

When a storm occurs, a portion of a rainfall infiltrates in to the ground and some portion may evaporate. The rest flows as a thin sheet of Water over the land Surface which is termed as overland flow.

If there is a relatively impermeable stratum in the subsoil, the infiltrating water moves laterally in the Surface Soil and joins the stream flow, which is termed as underflow. (subsurface flow) or interflow, as in fig below.

If there is no impending layer in the subsoil the infiltrating water percolates into the ground as deep seepage and build up the ground water table (GWT or phreatic surface). The groundwater may also contribute to the stream flow, if the GWT is higher than the

water surface level of the stream, creating a hydraulic gradient toward the stream. Low soil permeability favours overland flow. While all the three types of flow contribute to the stream flow, it is the overland flow, which reaches first the stream channel, the interflow being slower reaches after a few hours and the groundwater flow being the lowest reaches the stream channel after some days. The term direct runoff is used to include the overland flow and the interflow. If the snow melt contributes to the stream flow it can be included with the direct runoff (from rainfall).

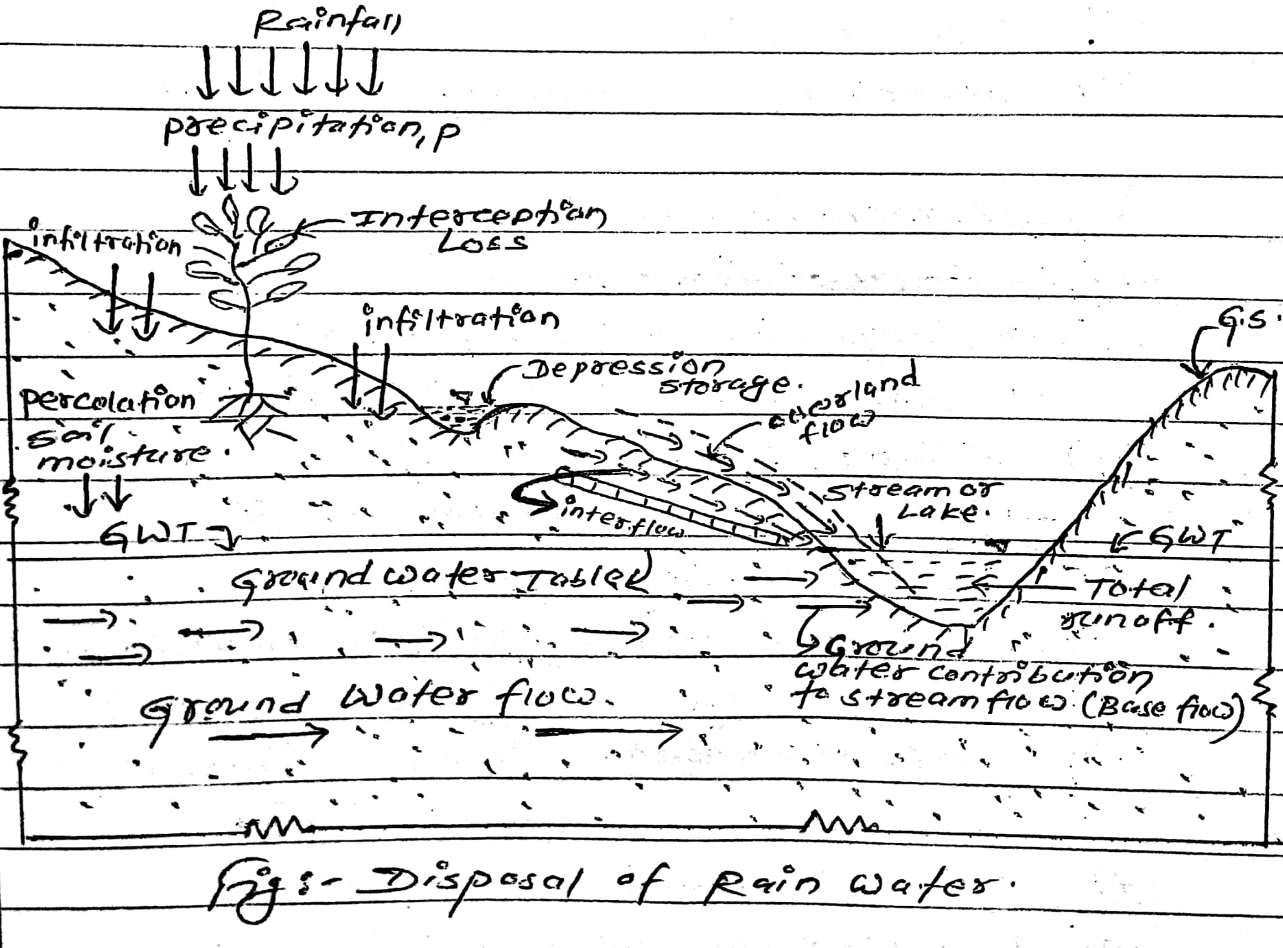


fig:- Disposal of Rain water.

Imp

Factor Affecting Run off :-

1. characteristics of basin.
2. characteristics of precipitation.

1. Characteristics of precipitation :-

(a) Types of precipitation

→ For rain : produce fast runoff

→ for snow : produce runoff at slow and steady rate.

(b) Rainfall intensity

→ High intensity of rainfall : runoff increases.

(c) Duration of Rainfall

→ Infiltration capacity decreases with increases in rainfall duration and after some times it becomes constant. so for longer duration of rainfall the runoff will be more even when it's intensity is medium.

(d) Rainfall distribution

(e) Direction of prevailing storm etc.

2. Characteristics of basin :-

(a) Size of basin

→ large basin : channel flow

→ Small basin : overland flow.

(b) Shape of basin

→ Fan shaped : greater runoff.

(c) Geology of basin

→ Lithologic factors : includes composition, texture of rocks.

→ Structural factors : includes presence of faults and folds.

(d) Slope of basin.

(e) Elevation

(f) Drainage density (DD)

→ fast response for high DD.

→ Slow response for low DD.

(g) Soil type.
(h) Soil moisture.
(i) Type of vegitative cover.

Rainfall-Runoff Relationship :-

The relationship between rainfall and the corresponding runoff is quite complex and is influenced by a host of factor relating to the catchment and climate. A commonly adopted method is to fit a linear regression line between runoff (R) and rainfall (P) and to acept the result if the correlation coefficient is nearer unity. The equation of the straight line regression between runoff R and rainfall P is

$$R = aP + b.$$

Value of coefficient 'a' and 'b' are given by;

$$a = \frac{N\Sigma(PR) - \Sigma(P)\cdot\Sigma(R)}{N\Sigma(P^2) - (\Sigma P)^2}$$

and,

$$b = \frac{\Sigma R - a\Sigma P}{N}$$

Where;

N = no. of observation

The coefficient of correlation r is;

$$r = \frac{N\Sigma(PR) - \Sigma P * \Sigma R}{\sqrt{\{N(\Sigma P^2) - (\Sigma P)^2\}\{N(\Sigma R^2) - (\Sigma R)^2\}}}$$

The value of 'r' lies between 0 and 1. If $0.6 < r < 1$ then it indicates good correlation

For large catchment, use expontial relationship as;

$$R = \beta P^m$$

Where, β and m are constant.

Stream guaging :-

The process of measuring discharge of a stream is called stream guaging.

Site selection for stream gauging :-

- The stream should have a well defined cross-section which doesnot change in various season.
- It should be easily accessible all through the year.
- The site should be in a straight, stable reach.
- The gauging site should be free from backwater effects.

Methods for determing the stream flow :-

1. Direct determination of stream discharge.
   - (a) Area-velocity method
   - (b) Dimension technique (salt concentration/chemical method).
   - (c) Electromagnetic method.
   - (d) Ultrasonic method.

2. Indirect determination of stream flow
   - (a) hydraulics structure (such as, weir, Notches, flumes & gated structure).
   - (b) Slope-area-method (To Estimate pick flood where no guaging station exists).

Stream flow measurement by Velocity Area method:

This method of discharge measurement consists of measuring the area of cross-section of the river at the guaging site and measuring the velocity of flow through the cross-section area. Here the cross section is considered to be divided into number of subsection by verticals. The average velocity in these subsection are measured by current meter or floats.

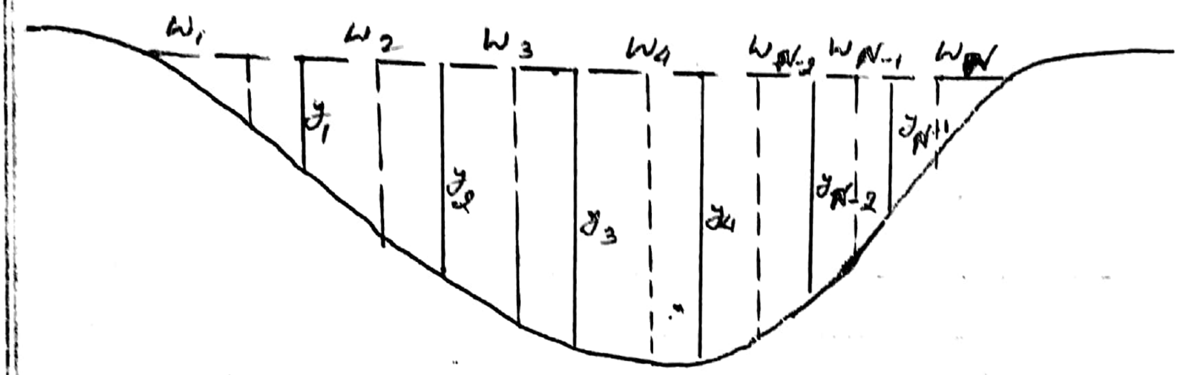


Fig:- Velocity area method.

Discharge $(\Delta q_1) = \Delta A_1 \times V_1$ $\quad [\Delta A_1 = \bar{W}_1 y_1]$

$\Delta q_{N-1} = \Delta A_{N-1} \times V_{N-1}$

$$q = \sum_{i=1}^{N} \Delta q_i .$$

Methods for measuring velocity :-

1. By current meter
   - cup type current meter
   - propeller type current meter
2. Velocity rod
3. Floats
   - surface
   - sub surface.

1. By current meter:-

- The current meter is widely used mechanical device for the measurement of flow velocity. there are two type of current meter.

(a) Cup type current meter:-

It consists of small wheel with cups at the periphery rotating about a vertical axis and a tail or fins to keep the instrument vertical. the cup type current meter can be handled by relatively unskilled technicians. the range of velocities measured by cup-type current meter is from 3 to 5 m/s.

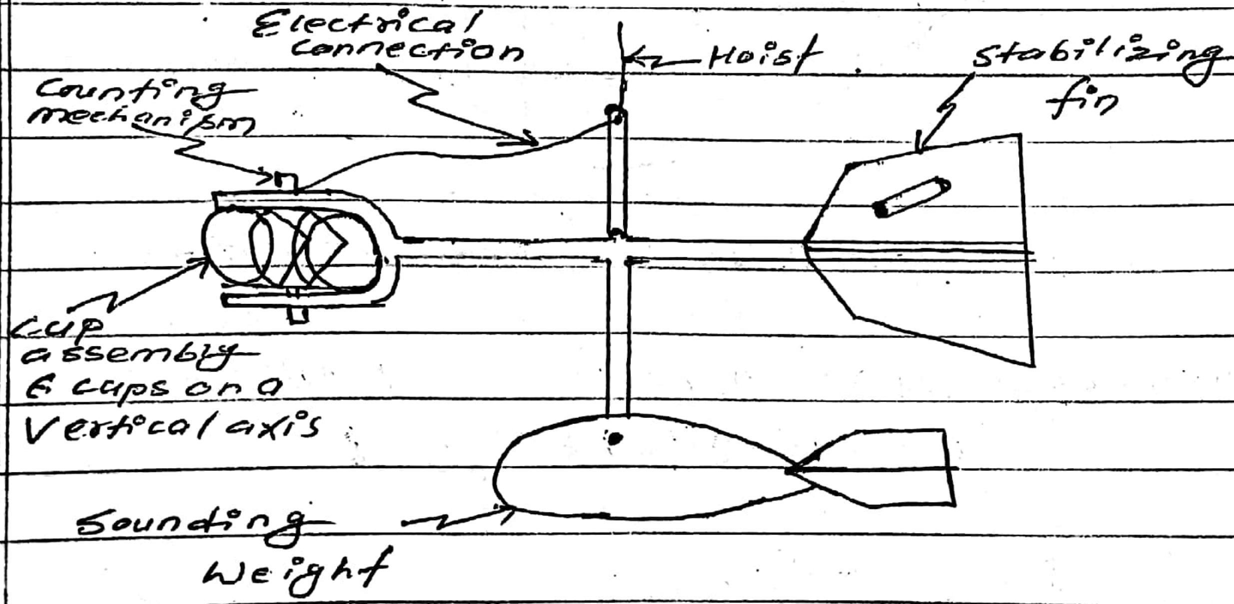


fig:- Vertical axis current meter.

(b) propeller type current meter:-

These meter consist of propeller mounted at the end of horizontal staff as shown in fig. Here propeller blades are rotated by the force of flowing water whose revolution for certain time is recorded and converted to stream velocity. the propeller type current meter has been

Used for relatively higher velocities (6 to 9 m/s)

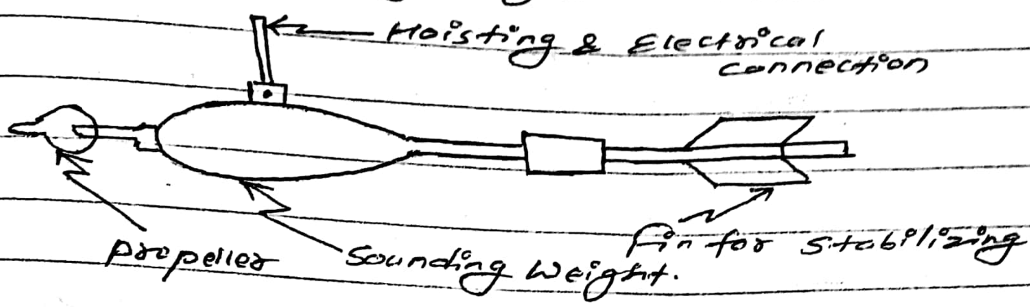


Fig:- Horizontal-axis current meter.

Imp **Calibration of current meter :-**

- The relation between the stream velocity and revolutions per second of the meter is called calibration Equation.

A current meter is so designed that its rotation speed varies linearly with the stream velocity V at the location of the stream. A typical relationship is

$$V = aN_s + b$$

Where;

V = stream velocity at the instrument location, m/s

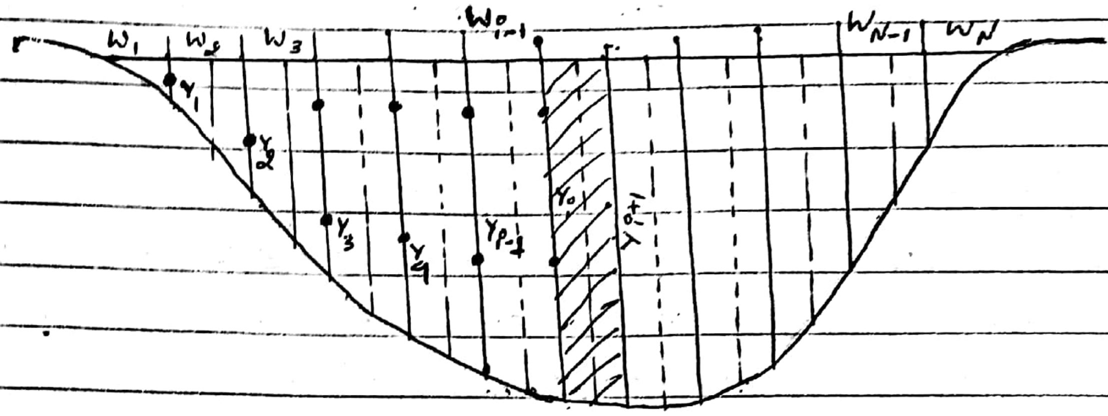
N_s = revolution per second of the meter and

a, b = constant of the meter.

The calibration equation is unique to each instrument and is determined by towing the instrument in a special tank. A towing tank is a long channel containing still water with arrangement for moving a carriage longitudinally over its surface at constant speed. The instrument to be calibrated is mounted on the carriage with the rotating element immersed

to a specified depth in the water body in the tank. The carriage is then towed at a predetermined constant speed (v) and the corresponding average value of revolution per second (N_s) of the instruments determined.

Imp Calculation of Discharge by Area Velocity method:



$$Q = \sum_{i=1}^{N-1} \Delta Q_i$$

Where, ΔQ_i = discharge in the i^{th} segment
= (depth at the i^{th} segment) × ($\frac{1}{2}$ width to the left + $\frac{1}{2}$ width to right) × average velocity at the i^{th} vertical

$$\Delta Q_i = y_i \times \left[\frac{W_i}{2} + \frac{W_{i+1}}{2}\right] \times v_i \quad \text{for } i = 2 \text{ to } (N-2)$$

For the first and last sections, the segments are taken to have triangular areas and area calculated as

$$\Delta A_1 = \bar{W}_1 \cdot y_1$$

Where, $\bar{W}_1 = \dfrac{\left(W_1 + \frac{W_2}{2}\right)^2}{2W_1}$ and $\Delta A_N = \bar{W}_{N-1} \cdot y_{N-1}$

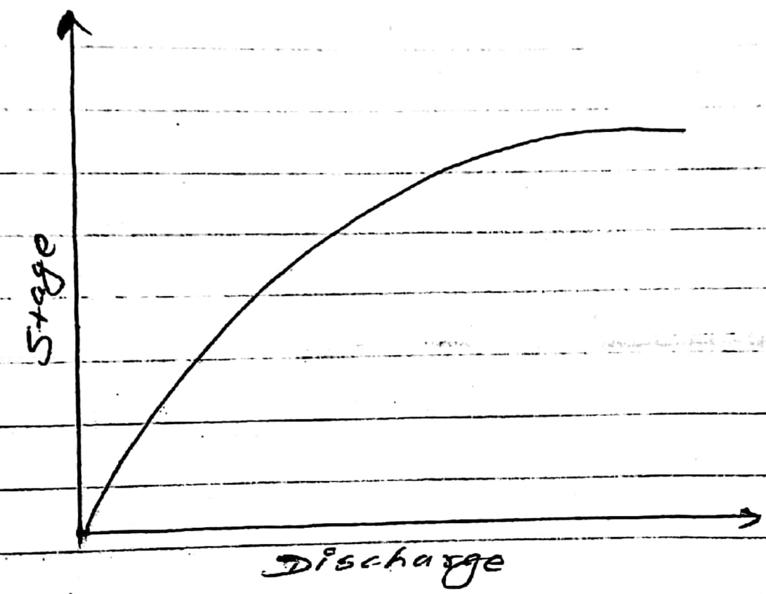
Where $\overline{W}_{N-1} = \dfrac{\left(W_N + \frac{W_{N-1}}{2}\right)^2}{2 W_N}$

to get

$$\Delta Q_1 = \overline{V}_1 \cdot \Delta A_1 \quad \text{and} \quad \Delta Q_{N-1} = \overline{V}_{N-1} \cdot \Delta A_{N-1}$$

Rating curve and it's uses :-

When the measured value of discharge is plotted against the corresponding stage a curve is obtained known as rating curve. Hence stage is plotted in y-axis and discharge in x-axis.



Equation of rating curve

The relationship between the stage and the discharge is a single valued relation which is expressed as;

$$Q = C_r (G-a)^{\beta}$$

Where; Q = stream discharge

G = stage

a = constant represent the gouge reading corresponding to zero discharge

C_r and β = rating curve constant.

The best value of C_r and β for a given range of stage are obtained by the least-square error method. Taking 'log' on both side.

$$\log \phi = \beta \log (G-a) + \log C_r$$

or, $\quad r = \beta x + b$

Where,

$$r = \log \phi$$

$$x = \log (G-a)$$

and, $\quad b = \log C_r$

Value of β and b;

$$\beta = \frac{N(\Sigma xy) - (\Sigma x)(\Sigma y)}{N(\Sigma x^2) - (\Sigma x)^2}$$

and,

$$b = \frac{\Sigma y - \beta(\Sigma x)}{N}$$; N = no. of observation

correlation coefficient 'r' is;

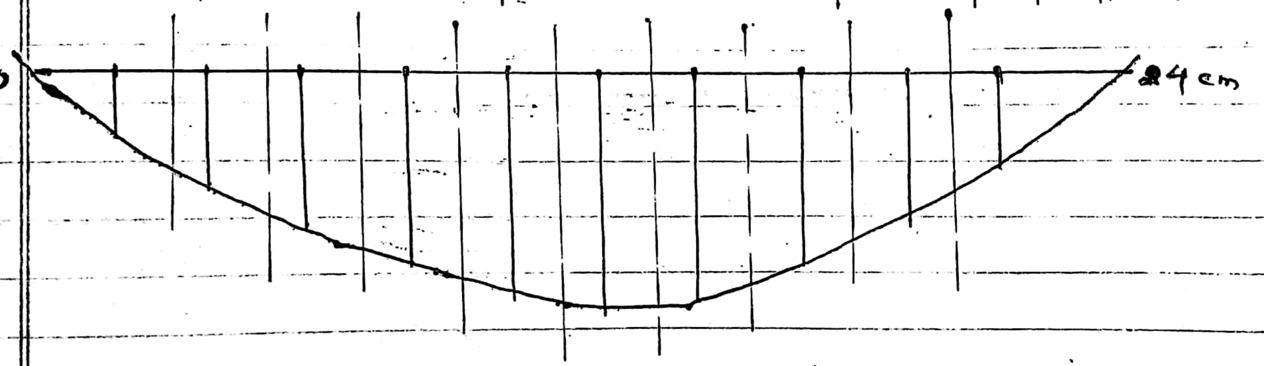
$$r = \frac{N(\Sigma xy) - (\Sigma x)(\Sigma y)}{\sqrt{[N(\Sigma x^2) - (\Sigma x)^2][N(\Sigma y^2) - (\Sigma y)^2]}}$$

K. Subramanya Ex. 4.3

Numerical parts :-

The following are the data obtained in a stream-gauging operation. A current meter with a calibration equation $V = (0.32N + 0.032)$ m/s, where N = revolutions per second was used to measure the velocity at 0.6 depth. Using the mid-section method, calculate the discharge in the stream.

Distance from right bank (m)	0	2	4	6	9	12	15	18	20	22	23	24
Depth (m)	0	0.50	1.10	1.95	2.25	1.85	1.75	1.65	1.50	1.25	0.75	0
Number of revolution	0	80	83	131	139	121	114	109	92	85	70	0
observation Time (s)	0	180	120	120	120	120	120	120	120	120	150	0



mid section method :-

The no. of segment = No. of depth

Average width of 1st section $= \dfrac{\left(W_1 + \frac{W_2}{2}\right)^2}{2W_1} = \dfrac{\left(2 + \frac{2}{2}\right)^2}{2 \times 2} = 2.25$

Average width of last section $= \dfrac{\left(1 + \frac{2}{2}\right)^2}{2 \times 1} = 1.125$

For other section, Avg. width $= \dfrac{W_i + W_{i+1}}{2}$.

Distance	Width of section	Avg. Width	Depth	Rev per second	Velocity $V = 0.32N + 0.032$	Cross section area	Segmental discharge
				—	—	—	—
0	0	—	—	0.444	0.174	1.125	0.1957
2	2	2.25	0.5	~~0.4744~~	0.253	2.2	0.5566
4	2	2	1.1	0.691	0.381	4.875	1.857
6	2	2.5	1.95	1.091	0.402	6.75	2.713
9	3	3	2.25	1.158	0.354	5.55	1.964
12	3	3	1.85	1.008	0.336	5.25	1.764
15	3	3	1.75	0.95	0.222	4.125	1.228
18	3	2.5	1.65	0.9083			
20	2	2	1.5	0.766	0.277	3	0.831
22	2	1.5	1.25	0.708	0.258	1.875	0.483
23	1	1.125	0.75	0.467	0.184	0.843	0.155
24	1	—	—	—	—	—	—

$\therefore$ Discharge $(Q) = 11.841\ m^3/s$.

H.M Raghunath Page no:- 189 Q.4(b)

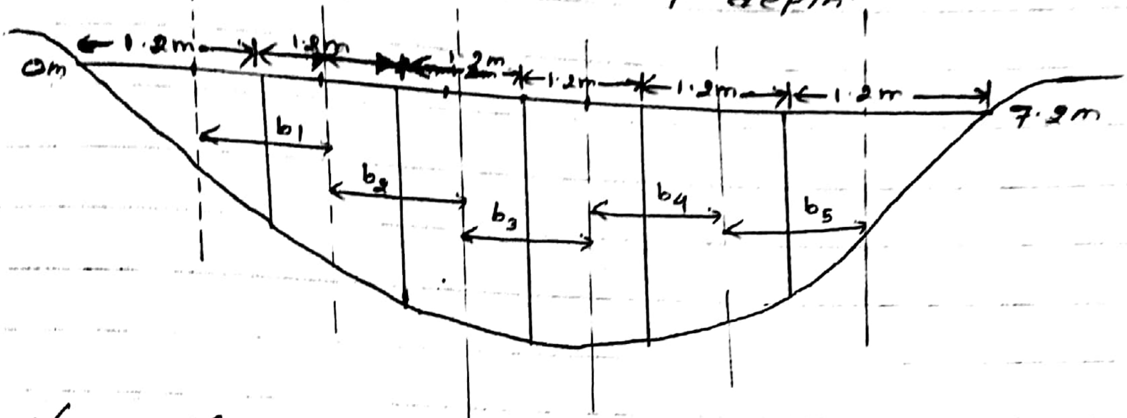
The following data were collected for a stream at a gauging station. Compute the discharge (i) mid-section method (ii) mean-section method.

Distance from one end of water surface (m)	Depth of water (m)	Velocity (m/sec) at 0.6d	at 0.2d	at 0.8d
0	0	—	—	—
1.2	0.7	0.4	—	—
2.4	1.7		0.7	0.5
3.6	2.5		0.9	0.6
4.8	1.3		0.6	0.4
6.0	0.5	0.35		
7.2	0	—	—	—

Solution:-

① mid-section method.

No. of segment = No. of depth.



Neglecting area of both side of the bank;

$q_1 = b_1 d_1 v_1 = 1.2 \times 0.7 \times 0.4$

$q_2 = b_2 d_2 v_2 = 1.2 \times 1.7 \times 0.6$ $\qquad V_{av} = \left[\frac{0.7+0.5}{2}\right] = 0.6$ m/sec.

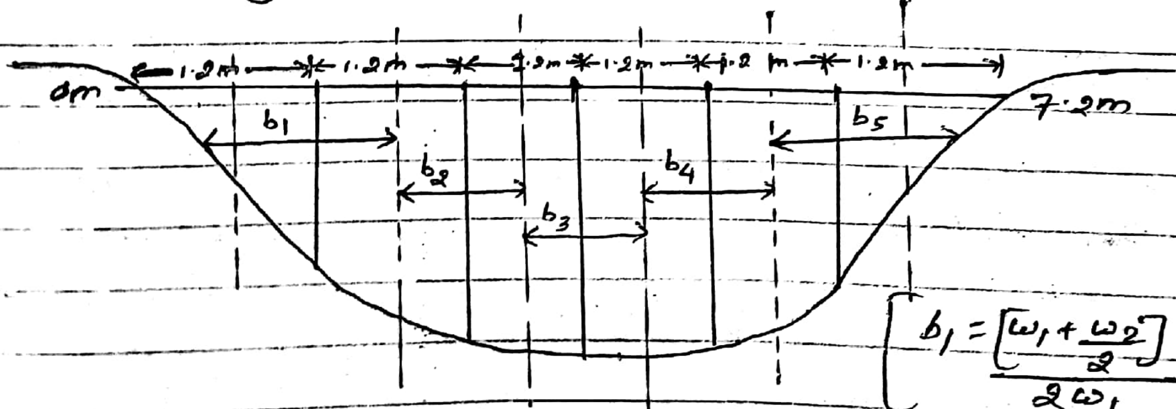
$q_3 = b_3 d_3 v_3 = 1.2 \times 2.5 \times 0.75$

$q_4 = b_4 d_4 v_4 = 1.2 \times 1.3 \times 0.5$

$q_5 = b_5 d_5 v_5 = 1.2 \times 0.5 \times 0.35$

$Q = q_1 + q_2 + q_3 + q_4 + q_5 = 4.8\ m^3/sec.$

Considering the area of both sides of bank.



$$b_1 = \left[\frac{\left[w_1 + \frac{w_2}{2}\right]^2}{2w_1}\right]$$

$$b_1 = \frac{\left(w_1 + \frac{w_2}{2}\right)^2}{2w_1} = \frac{\left(1.2 + \frac{1.2}{2}\right)^2}{2 \times 1.2} = 1.35\ m$$

$$b_5 = \left[\frac{w_6 + \frac{w_5}{2}}{2w_6}\right]$$

$$b_5 = \frac{\left(1.2 + \frac{1.2}{2}\right)^2}{2 \times 1.2} = 1.35\ m$$

$q_1 = b_1 d_1 v_1 = 1.35 \times 0.7 \times 0.4$

$q_2 = b_2 d_2 v_2 = 1.2 \times 1.7 \times 0.6$

$q_3 = b_3 d_3 v_3 = 1.2 \times 2.5 \times 0.75$

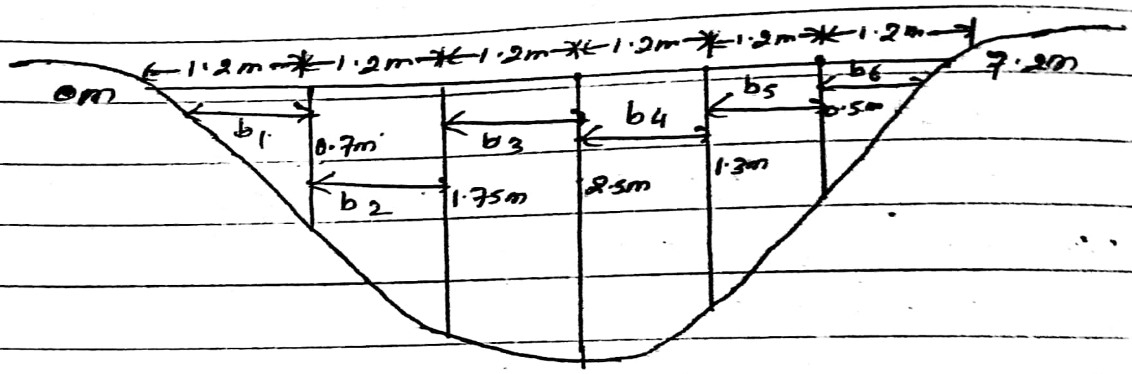
$q_4 = b_4 d_4 v_4 = 1.2 \times 1.3 \times 0.5$

$q_5 = b_5 d_5 v_5 = 1.35 \times 0.5 \times 0.35$

$q = q_1 + q_2 + q_3 + q_4 + q_5 = 4.8625 \ m^3/sec.$

(2) Mean section method :-

No. of segment = (No. of depth + 1).



$q_1 = b_1 d_1 v_1 = 1.2 \times \left[\frac{0+0.7}{2}\right] \times \left(\frac{0+0.4}{2}\right)$

$q_2 = b_2 d_2 v_2 = 1.2 \times \left[\frac{0.7+1.75}{2}\right] \times \left(\frac{0.4+0.6}{2}\right)$

$q_3 = b_3 d_3 v_3 = 1.2 \times \left[\frac{1.7+2.5}{2}\right] \times \left(\frac{0.6+0.75}{2}\right)$

$q_4 = b_4 d_4 v_4 = 1.2 \left[\frac{2.5+1.3}{2}\right] \times \left(\frac{0.75+0.5}{2}\right)$

$q_5 = b_5 d_5 v_5 = 1.2 \times \left[\frac{1.3+0.5}{2}\right] \times \left(\frac{0.5+0.35}{2}\right)$

$q_6 = b_6 d_6 v_6 = 1.2 \times \left[\frac{0.5+0}{2}\right] \times \left(\frac{0.35+0}{2}\right)$

$q = q_1 + q_2 + q_3 + q_4 + q_5 + q_6 = 4.442 \ m^3/sec.$

During a high flow water-surface elevation of a small stream were noted at two section A and B 10km apart. These elevations and other silent hydraulic properties are given below.

Section	Water surface Elevation	Area of cross-section	Hydraulic radius	Remarks
A	104.771	73.293	2.733	A is upstream of B.
B	104.5	93.375	3.089	

$n = 0.02$, the Eddy Loss coefficient of 0.3 for gradual Expansion and 0.1 for gradual contraction are appropriate.

Solution:-

Section A

$A_1 = 73.293 m^2$

$R_1 = 2.733 m$

$K_1 = \frac{1}{n} A_1 R_1^{2/3}$

$= \frac{1}{0.02} \times 73.293 \times 2.733^{2/3}$

$= 7163.5$

Section B

$A_2 = 93.375 m^2$

$R_2 = 3.089 m$

$K_2 = \frac{1}{n} A_2 R^{2/3}$

$= \frac{1}{0.02} \times 93.375 \times 3.089^{2/3}$

$= 9902.52$

Average conveyance $(K) = \sqrt{K_1 K_2} = \sqrt{7163.5 \times 9902.52}$

$= 8422.4$

We have;

Head loss $(h_f) = h_1 - h_2 + \left(\frac{V_1^2}{2g} - \frac{V_2^2}{2g}\right) - h_e$

For initial start;

$h_f = 104.771 - 104.5 = 0.271 m$

Length of reach (given) $L = 10km = 10{,}000 m$.

$\therefore \quad \bar{S}_f = \frac{h_f}{L} = \frac{0.271}{10000} = 2.71\times10^{-5}$

And, $\quad Q = K\sqrt{\bar{S}_f}$

$V_1 = \frac{Q}{A_1} \quad , \quad V_2 = \frac{Q}{A_2}$

Here, since area of cross section at B is greater than that of A (i.e. $A_2 > A_1$) so, there is gradual Expansion so, eddy coefficient, $k_e = 0.3$.

$\therefore \quad h_f = (h_1 - h_2) + \left(\frac{V_1^2}{2g} - \frac{V_2^2}{2g}\right) - k_e\left(\frac{V_1^2}{2g} - \frac{V_2^2}{2g}\right).$

Trails :-

Trial	h_f	S_f	Q	V_1	V_2	New h_f
1	0.271	2.71×10^{-5}	43.845	0.598	0.469	0.27591
2	0.27591	2.759×10^{-5}	44.24	0.603	0.473	0.2759
3	0.2759	2.759×10^{-5}	44.24	0.603	0.473	0.2759

Here, different in h_f for trial 2 and 3 is negligible.

So, Discharge (Q) = 44.24 m^3/s.

K. Subramanya Example 4.3

During a flood flow the depth of water in 10m wide rectangular channel was found to be 3.0m and 2.9m at two section 200m apart. The drop in the water surface elevation was found to be 0.12m. Assuming manning's coefficient to be 0.025, estimate the flood discharge through the channel.

Solution:-

Section 1

Depth $(y_1) = 3m$

Width $(B) = 10m$

Area $(A_1) = By_1 = 10\times3 = 30m^2$

Wetted perimeter $= B+2y_1$

$= 16m$

Hydraulic Radius $(R_1) = \left(\frac{A_1}{P_1}\right)$

$= \left(\frac{30}{16}\right)$

$= 1.875m$

Conveyance $(K_1) = \frac{1}{n} A_1 R_1^{2/3}$

$= \frac{1}{0.025} \times 30 \times 1.875^{2/3}$

$= 1824.66$

Section 2

Depth $(y_2) = 2.9m$

Width $(B) = 10m$

Area $(A_2) = 10\times2.9 = 29m^2$

Wetted perimeter $(P_2) = B+2y_2$

$= 15.8m$

Hydraulic Radius $(R_2) = \frac{A_2}{P_2}$

$= \frac{29}{15.8}$

$= 1.835m$

Conveyance $(K_2) = \frac{1}{n} A_2 R_2^{2/3}$

$= \frac{1}{0.025} \times 29 \times 1.835^{2/3}$

$= 1738.66$

$\therefore$ Average $k = \sqrt{k_1 k_2}$

$= \sqrt{1824.66 \times 1738.66}$

$= 1781.14$

h_e = Eddy coefficient = 0 (not given)

Here, fall (h_f) = start with 0.12, Which is drop in Elevation

$\therefore \bar{S}_f = \frac{h_f}{L} = \frac{0.12}{200} = 6\times10^{-4}$

So, $Q = K\sqrt{\bar{S}_f} = 1781.14\sqrt{\bar{S}_f}$

Trial	h_f	S_f	Q	$\frac{V_1^2}{2g}$	$\frac{V_2^2}{2g}$	$h_f = 0.12 + \left(\frac{V_1^2}{2g} - \frac{V_2^2}{2g}\right)$
1	0.12	6×10^{-4}	43.63	0.1078	0.1154	0.1124
2	0.1124	5.622×10^{-4}	43.29	0.101	0.1081	0.1129
3	0.1129	5.646×10^{-4}	43.32	0.1014	0.1081	0.1129

$\therefore$ Actual discharge $(Q) = 43.32\ m^3/s$.

K. Subramanya Ex. 4.10

~~During~~ A small stream has a trapezoidal cross-section with base width of 12m and side slope 2 horizontal : 1 vertical in a reach of 8km. During a flood high water record at the ends of the reach are as follows.

Section	Elevation of bed	Water surface Elevation	Remarks
1.	100.2	102.7	$n = 0.03$.
2.	98.6	101.3	

Solution:-

Section A

Bed level = 100.2

Water level = 102.7

Water depth $(y_1) = 102.7 - 100.2 = 2.5m$

Cross-section area $(A_1) = (b + zy_1)y_1$

$= (12 + 2 \times 2.5) \times 2.5 = 42.5m^2$.

Wetted perimeter $(P_1) = b + 2y_1\sqrt{1+z^2}$

$= 12 + 2 \times 2.5\sqrt{1+2^2}$

$= 23.18m$

$\therefore$ Hydraulic radius $(R_1) = \frac{A_1}{P_1} = \frac{42.5}{23.18} = 1.833m$

$\therefore k_1 = \frac{1}{n} A_1 R_1^{2/3} = \frac{1}{0.03} \times 42.5 \times 1.833^{2/3} = 2122.19$

Section B

Bed level = 98.6m

Water level = 101.3m

Water depth $(y_2) = 101.3 - 98.6 = 2.7m$

Cross-section Area $(A_2) = (b + zy_2)y_2$

$= (12 + 2 \times 2.7) \times 2.7$

$= 46.98m^2$.

Wetted perimeter $(P_2) = b+2y_2\sqrt{1+z^2}$

$= 12+2\times2.7\sqrt{1+2^2}$

$= 24.07m.$

$\therefore$ Hydraulic radius $(R_2) = \frac{A_2}{P_2} = \frac{46.98}{24.07} = 1.951m.$

$\therefore$ Conveyance $(K_2) = \frac{1}{n}A_2R_2^{2/3} = \frac{1}{0.03}\times46.98\times1.951^{2/3}$

$= 2445.099.$

Therefore;

Average conveyance $(K) = \sqrt{K_1K_2}$

$= \sqrt{2122.19\times2445.099}$

$= 2277.929.$

Therefore;

For head loss

$$h_f = (h_1-h_2)+\left(\frac{V_1^2}{2g}-\frac{V_2^2}{2g}\right)-h_e$$

Here, $h_e=0$ (since not given), so, $h_f = h_1-h_2+\left(\frac{V_1^2}{2g}-\frac{V_2^2}{2g}\right).$

For initial start,

$H_f = h_1-h_2 = 102.7-101.3 = 1.4\ m$ (Assume, $V_1=V_2$)

$\therefore\ S_f = \left(\frac{h_f}{L}\right) = \left(\frac{1.4}{800}\right) = 1.75\times10^{-4}$

Formula used: $S_f = \frac{h_f}{L}$, $Q = K\sqrt{S_f}$, $V_1 = \frac{Q}{A_1}$, $V_2 = \frac{Q}{A_2}$

Now,

$$h_f = 1.4+\left[\frac{V_1^2}{2g}-\frac{V_2^2}{2g}\right].$$

Trial	h_f	S_f	Q	V_1	V_2	New h_f
1	1.4	1.75×10^{-4}	30.134	0.709	0.641	1.40467
2	1.40467	1.755×10^{-4}	30.177	0.71	0.642	1.4046

Here, the different in value of h_f from trial 1 & 2 is negligible.

So, Discharge $(Q) = 30.117\ m^3/s$.

Chapter:- 7:- Hydrograph Analysis:-

Defination :-

A hydrograph is a plot of the runoff or discharge in a stream versus time.

Hydrograph is a graphical plot between discharge (on y-axis) and the corresponding time.

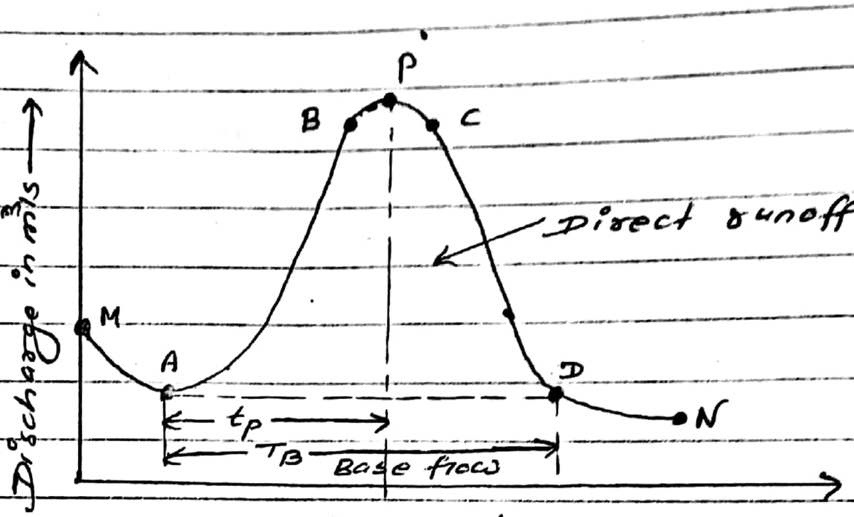


Fig:- Element of hydrograph.

Component of hydrograph:-

1. The rising limb:-
It is the curve or line joining the starting point 'A' of the raising curve and the point of reflection 'B'.

2. peak or crest:-
It represents the highest point of the hydrograph. It is one of the most important parts of a hydrograph as it contains the peak flow.

3. Time to peak (t_p):-
It is the time to peak from the starting point of hydrograph

4. Lag time :-
The time interval from the center of mass of rainfall to the center of moss of hydrograph is the Lag time.

Separtion of Base Flow :-

Direct runoff :-
portion of the total runoff hydrograph at a stream which is caused by and direcrly following a rainfall or Snowmelt event.

Base Flow :-
portion of the total runoff hydrograph at a stream location which is composed of contribution from ground water runoff delayed interflow.

Imp

methods of base flow-separation :-

method 1 - Straight Line method
In this method the separation of base flow is achieved by joining with a straight Line the beginning of the surface runoff to a point on the recession limb representing the end of the direct runoff. In fig point 'A' represents the beginning of the direct run-off and point B represents the end of the direct runoff. the Emperical Equation is used to find point B.

$$N = 0.83 A^{0.2}$$

A = drainage area in km^2 and N is in days.

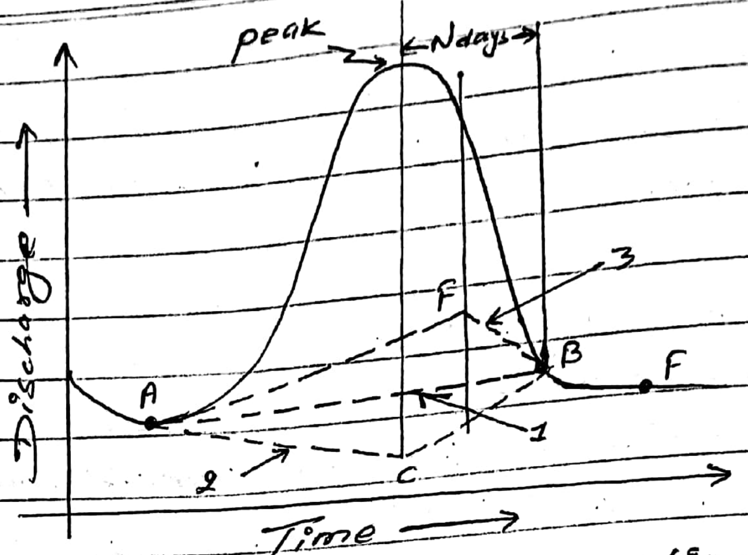


Fig:- Base Flow separation.

method 2

In this method the base flow curve existing prior to the commencement of the surface runoff is extended till it intersect the ordinate drawn at the peak. Join this point 'C' to point A and segment AC and CB demarcate the base flow and surface runoff

method 3

Extend a point on the recession curve backword up to a point 'F' directly below the inflection point and join AF.

Unit hydrograph and their Uses :-

- A unit hydrograph is the direct runoff hydrograph resulting from one centimeter (or 1mm or 1 inch) of Excess rainfall generated uniformly over a catchment area at a constant rate for an effective duration (D-hours).

Uses of Unit hydrograph :-

Unit hydrograph is useful for,

1. Development of flood hydrograph for extreme rainfalls for use in the design of hydraulic structures.
2. Extension of flood-flow records based on rainfall data.
3. Development of flood forecasting and warning system based on rainfall.

Numerical parts :-

ramanya
x. 6.7

The following are the ordinates of hydrograph of flow from catchment area of 770 km^2 due to 6-h rainfall. Derive the ordinates of the 6-h unit hydrograph. Make suitable assumption regarding the base flow.

Time from beginning of storm (h)	0	6	12	18	24	30	36	42	48	54	60	66	72
Discharge (m^3/s)	40	65	215	360	400	350	270	205	145	100	70	50	42

T.U.M. Raghunath

Derive the unit hydrograph from a given flood hydrograph. Also find area of catchment.

t (hr)	0	3	6	9	12	15	18	21	24	27
T.R.O (m^3/s)	3	9	21	37.4	51	40.6	21.4	12.2	6.2	3

Given P_{net} = 4 cm of 3 hr.

Solution:-

t (hr)	T.R.O (m^3/s)	B.F.O (m^3/s)	D.R.O of P_{net} 4cm of 3 hr duration	D.R.O of P_{net} 1 cm of 3 hr. i.e. 3 hr-UHO.
0	3	3	0	0
3	9	3	6	6/4 = 1.5
6	21	3	18	18/4 = 4.5
9	37.4	3	34.4	8.6
12	51	3	48	12.0
15	40.6	3	37.6	9.4
18	21.4	3	18.4	4.6
21	12.2	3	9.2	2.3
24	6.2	3	3.2	0.8
27	3	3	0	0
			$\boxed{\Sigma q_d = 174.8\ m^3/se}$	

$$\left[\begin{array}{l} 4\,cm \Rightarrow 6\,m^3/s \\ 1\,cm \Rightarrow \frac{6}{4}\,m^3/s \end{array}\right]$$

We know that; T.R.O = D.R.O + B.f.O.

$\therefore$ D.R.O = T.R.O − B.f.O.

Again;

We know that; $$P_{net} = \frac{\Sigma q_d \times \Delta t}{A}$$

$$A = \frac{\Sigma q_d \times \Delta t}{P_{net}}$$

$$A = \frac{174.8 \times 3 \times 3600}{4 \times 10^{-2}} = 47196000$$

$\therefore A = 47.196\ km^2$ Ans

H.M. Raghunath

Derive the stream flow due to three sucessive Storm of 3.5, 4.5 and 2.5 cm of 6 hour duration each on a basin. Assuming a constant base flow of 10 cumecs and an average storm Loss of 0.25 cm/hour. The 6 hour unit hydrograph for the basin is given below. Also calculate the Area of catchment.

t(hr)	0	3	6	9	12	15	18	21	24	27
6hr-UGO m^3/sec	0	2	4	8	12	9	4	2	1	0

Solution:- given:-

$P_1 = 3.5$ cm of duration 6hr.
$P_2 = 4.5$ cm of duration 6hr.
$P_3 = 2.5$ cm of duration 6hr.

Base Flow (B.f.o.) = 10 cumecs = $10 m^3/sec$.
Losses = 0.25 cm/hr.

T.R.O = ?

$P_{net_1} = P_1 - \text{losses}$
$= 3.5 - 0.25 \times 6$
$= 2$ cm

$P_{net_2} = P_2 - \text{losses}$
$= 4.5 - 0.25 \times 6$
$= 3$ cm

$P_{net3} = 2.5 - 1.5$
$= 1$ cm.

t(hr)	6hr-U.G.O. m^3/sec	D.R.O. (m^3/s) of P_{net_1} 2cm of 6-hr duration	P_{net_2} 1cm of 6-hr duration lagged by 6hr.	P_{net_3} 1cm of 6-hr duration lagged by 12hr.	Total D.R.O m^3/sec	B.F.O m^3/sec	T.R.O m^3/sec
0	0	0	–	–	0	10	10
3	2	2×2 = 4	~~0×3=0~~	–	4	10	14
6	4	4×2 = 8	[illegible]×3=[illegible]	–	8	10	18
9	8	16	2×3=6	–	22	10	32
12	12	24	12	0	36	10	46
15	9	18	24	2×1=2	44	10	54
18	4	8	36	4×1=4	48	10	58
21	2	4	27	8	39	10	49
24	1	2	12	12	26	10	36
27	0	0	6	9	15	10	25
30			3	4	7	10	17
33			0	2	2	10	22
36				1	1	10	11
39				0	0	10	10

We know that;

$$P_{net} = \frac{\Sigma q_d \times \Delta t}{A}$$

If P_{net_1} is taken $\Sigma q_d = (4+8+16+\cdots\cdots+2+0) = 84\ m^3/s$

$P_{net_1} = 2cm$

So,

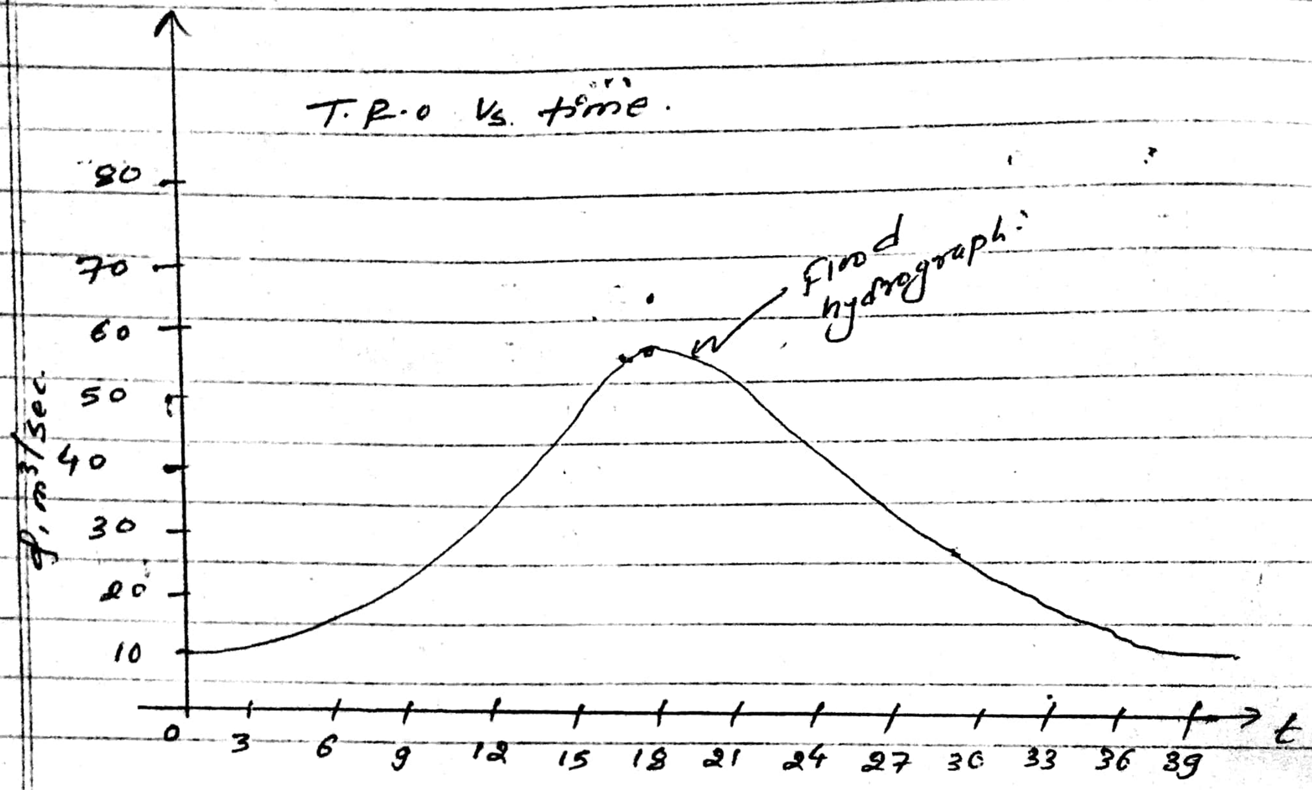
$$2\times10^{-2} = \frac{84\times3\times3600}{A}, \quad A = 45.360\ km^2$$

If U.G.O is taken;

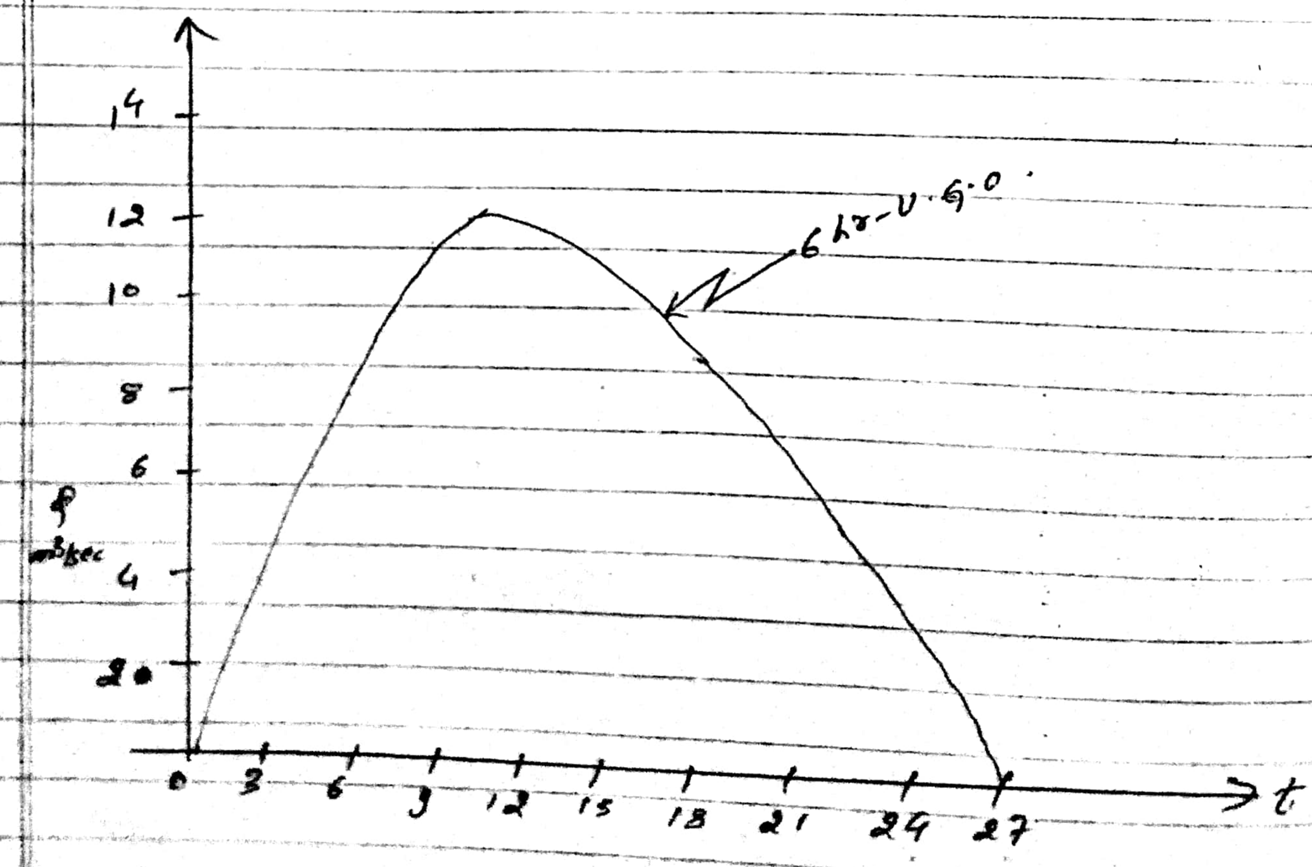
$P_{net} = 1cm$, $\Sigma q_d = 0+2+4+8+12+9+4+2+1+0 =$

So, $$1\times10^{-3} = \frac{42\times3\times3600}{A}, \quad A = 45.360\ km^2.$$

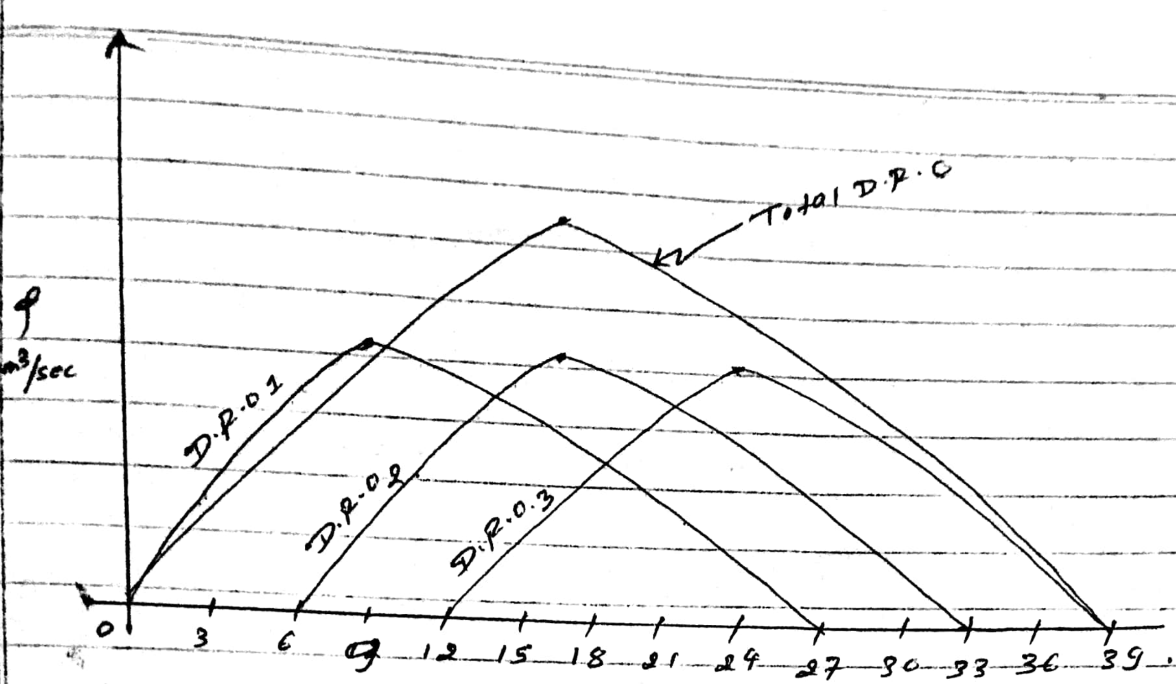
Graph



T.R.O Vs. time.
Flood hydrograph.
Q, m³/sec
80
70
60
50
40
30
20
10
0
3
6
9
12
15
18
21
24
27
30
33
36
39
t



6 hr-U.G.O.
Q m³/sec
14
12
10
8
6
4
2
0
3
6
9
12
15
18
21
24
27
t



H.M. Raghunath

The stream flow due to the three sucessive storm 3.5, 4.5 & 2.5cm of 6-hr duration each on a basin are given below. The area of basin is 45.4 km² assuming a constant base flow of 10 cumecs and average storm loss of 0.25 cm/hr. Derive the ordinates of 6-hr unit hydrograph for the basin.

Solution:-

$P_1 = 3.5$ cm of 6-hr duration

$P_2 = 4.5$ cm of 6-hr duration

$P_3 = 2.5$ cm of 6-hr duration

Base flow (B.f.o) = 10 cumecs = 10 m³/sec.

Losses = 0.25 cm/hr.

$P_{net_1} = P_1 - \text{Losses} = 3.5 - 0.25 \times 6 = 2$ cm

$P_{net_2} = P_2 - \text{Losses} = 4.5 - 0.25 \times 6 = 3$ cm

$P_{net_3} = P_3 - \text{Losses} = 2.5 - 0.25 \times 6 = 1$ cm

t(hr)	6-hr UGO (cm³/sec)	DRO of Pnet 2cm of 6hr duration	Pnet 3cm of 6-hr lagged by 6hr	Pnet 1cm of 6-hr lagged by 12hr	Total D.R.O.	D.R.O.=TRO−Bfo	Bfo m³/sec	T.R.O. m³/sec
0	0	0	–	–	0	0	10	10
3	u_1	$2u_1$	–	–	$2u_1$	4	10	14
6	u_2	$2u_2$	0	–	$2u_2$	8	10	18
9	u_3	$2u_3$	$3u_1$	–	$2u_3+3u_1$	22	10	32
12	u_4	$2u_4$	$3u_2$	0	$2u_4+3u_2$	36	10	46
15	u_5	$2u_5$	$3u_3$	u_1	$2u_5+3u_3+u_1$	44	10	54
18	u_6	$2u_6$	$3u_4$	u_2	$2u_6+3u_4+u_2$	48	10	58
21	u_7	$2u_7$	$3u_5$	u_3	$2u_7+3u_5+u_3$	39	10	49
24	u_8	$2u_8$	$3u_6$	u_4	$2u_8+3u_6+u_4$	26	10	36
27	u_9	$2u_9$	$3u_7$	u_5	$2u_9+3u_7+u_5$	15	10	25
30	u_{10}	$2u_{10}$	$3u_8$	u_6	$2u_{10}+3u_8+u_6$	7	10	17
33	u_{11}	$2u_{11}$	$3u_9$	u_7	$2u_{11}+3u_9+u_7$	2	10	12
36	u_{12}	$2u_{12}$	$3u_{10}$	u_8	$2u_{12}+3u_{10}+u_8$	1	10	11
39	0	0	$3u_{11}$	u_9	$3u_{11}+u_9$	0	10	10
42			$3u_{12}$	u_{10}	$3u_{12}+u_{10}$			
45			0	u_{11}	u_{11}			
48				u_{12}	u_{12}			
51				0	0			

Equation DRO to D.R.O.

$2u_1 = 4, \quad u_1 = 2$

$2u_2 = 8, \quad u_2 = 4$

$2u_3 + 3u_1 = 22, \quad u_3 = 8.$

Similarly:

$u_4 = 12, \; u_5 = 9, \; u_6 = 4, \; u_7 = 2, \; u_8 = 1, \; u_9 = 0, \; u_{10} = 0;$

$u_{11} = 0, \quad u_{12} = 0$ Ans.

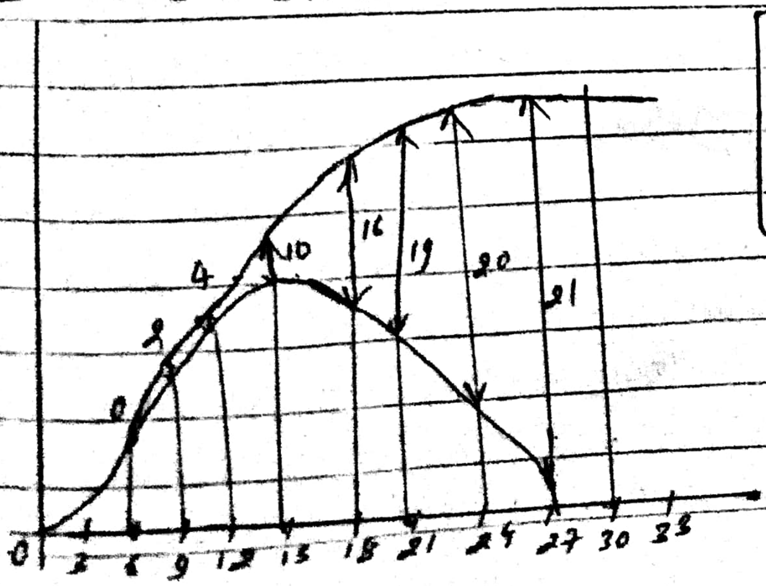
Changing a D-hr-U.G.O in to T-hr-UGO for a given 6-hr UGO. Derive the 12-hr U.G.O and 3-hr. UGO.

Solution:- Here, $\frac{D}{T} = \left(\frac{6}{12}\right)$.

Col. 1 t(hr)	Col. 2 6-hr. UGO m^3/sec.	Col. 3 S-curve addition	Col. 4 S-curve (m^3/sec)	Col. 5 S-curve lagged by 12 hr (m^3/sec)	Col. 6 S-curve difference: Col. 4 - Col. 5	Col. 7 12-hr UGO Col. 6 * $\frac{D}{T}\left(\frac{6}{12}\right)$
0	0	-	0	-	0	$0 \times \frac{6}{12} = 0$
3	2	-	2	-	2	$2 \times \frac{6}{12} = 1$
6	4	0	4+0=4	-	4	$4 \times \frac{6}{12} = 2$
9	8	2	8+2=10	-	10	5
12	12	4	12+4=16	0	16	8
15	9	10	9+10=19	2	17	8.5
18	4	16	4+16=20	4	16	8
21	2	19	2+19=21	10	11	5.5
24	1	20	1+20=21	16	5	2.5
27	0	21	0+21=21	19	2	1
30			21	20	1	0.5
33			21	21	0	0
36			21	21	0	
39			21	21	0	

[Not necessary to see]

S-curve method



Note :- From supperposition method

$m * D = T$

$2 \times 6 = 12$ hr-UGO

K. Subramanya

Given below are stream flow from a catchment area of 20 km² due to a storm of 1-hour duration. Find the flood hydrograph ordinates from an effective rainfall 6 cm of duration 1 hour. Assume a constant base flow 10 m³/sec.

Solution:-

t (hr)	Q, m³/s (T.R.O)	B.f.O.	D.R.O of Pnet 3.22 cm of 1 hr	1-hr UGO m³/s	D.R.O of Pnet 6 cm of 1 hr	Bfo m³/sec	T.R.O = DRO + Bfo
0	15	15	0	0/3.22 = 0	0	10	10
1	25	15	10	10/3.22 = 3.10	3.10×6 = 18.6	10	28.6
2	50	15	35	35/3.22 = 10.87	10.87×6 = 65.52	10	75.52
3	55	15	40	12.42	74.52	10	84.52
4	48	15	33	10.24	61.44	10	71.44
5	35	15	20	6.21	37.26	10	47.26
6	30	15	15	4.65	27.9	10	37.9
7	27	15	12	3.72	22.32	10	32.32
8	24	15	9	2.79	26.74	10	36.74
9	20	15	5	1.55	9.3	10	19.3
10	15	15	0	0	0	10	10

Here,

$$P_{net} = \frac{\Sigma Q_d * \Delta t}{A} = \frac{179 \times 3600}{20 \times 10^6} = 0.0322 m = 3.22 cm.$$

Q. For a given 6-hr UGO. Derive the 3-hr U.G.O by Superposition and S-curve method.

Solution:-

Supperposition method:-

~~For~~ For 6-hr below, we can not findout the U.G.O. So in this case ~~So~~ S-curve method is apply.

S-curve method

col 1 t(hr)	col. 2 6-hr-UGO (m^3/sec)	col. 3 S-curve addition	col. 4 S-curve (m^3/sec)	col. 5 S-curve lagged by 3-hr (m^3/sec)	col. 6 S-curve difference col.4-col.5	col. 7 3-hr-UGO = col 6 × $\frac{D}{T}$ $\left(\frac{6}{3}\right)$
0	0	-	0	-	0	$0 \times 6/3 = 0$
3	2	-	2	0	2	$2 \times 6/3 = 4$
6	4	0	4+0=4	2	2	$2 \times 6/3 = 4$
9	8	2	8+2=10	4	6	$6 \times 6/3 = 12$
12	12	4	16	10	6	12
15	9	10	19	16	3	6
18	4	16	20	19	1	2
21	2	19	21	20	1	2
24	1	20	21	21	0	0.
27	0	21	21	21		
30			21	21		
33			21			
36			21			
39			21			

H.M. Raghunath

A steady 6-hr rainfall with an intensity of 4cm/hr produces a peak discharge of 560 cumecs. The average storm loss can be assumed as 1cm/hr and base flow 20 cumecs, What is the peak discharge of the unit hydrograph and it's duration. On the same basin, determine the peak discharge from a 6-hr rainfall of an intensity of 3.5 cm/hr Assuming an average loss rate of 1.5 cm/hr and base flow of 15 cumecs.

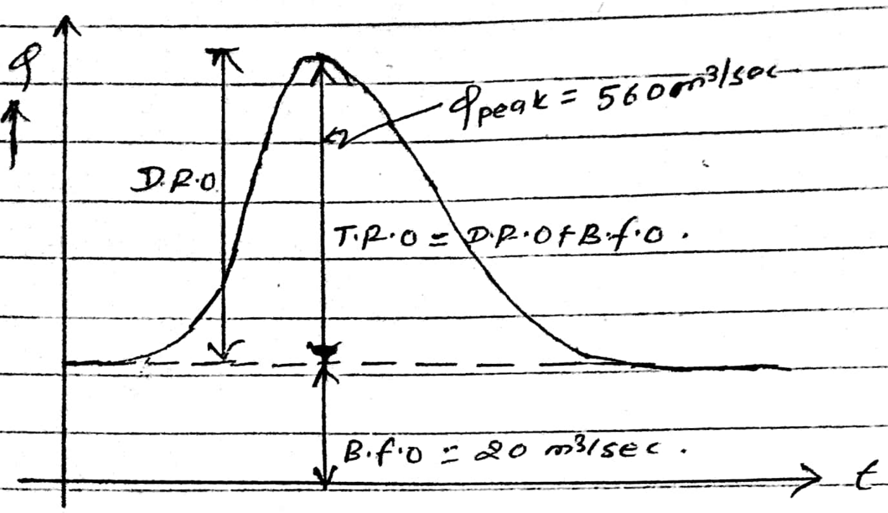
Solution:- Given:-

$P_1 = 4\,cm/hr \times 6\,hr = 24\,cm$, Losses = 1cm/hr × 6hr = 6cm

$P_{net_1} = P_1 - Losses = (24-6)\,cm = 18\,cm$

Base flow (B.f.o.) = 20 m³/sec.

q_{peak} = 560 cumecs = 560 m³/sec.



D.R.O = T.R.O − B.f.O

= (560 − 20) m³/sec

= 540 m³/sec.

In P_{net} of 18 cm, 540 m³/sec is occured.

For 1 cm P_{net} i.e, U.G.O.;

U.G.O = $\left(\frac{540}{18}\right)$ m³/sec = 30 m³/sec. of 1 cm rain fall of duration 6-hr.

Again;

P = 3.5 cm/hr × 6 hr = 21 cm

Losses = 1.5 cm/hr × 6 hr = 9 cm

P_{net} = P − Losses = (21 − 9) cm = 12 cm.

In 1 cm, 30 m³/sec, so for 12 cm (i.e, D.R.O)

D.R.O. = 30 m³/sec × 12 cm = 360 m³/sec.

T.R.O = D.R.O + B.f.O.

= (360 + 15) m³/sec

= 375 m³/sec

Ans.

ordinates of 1hr-unit hydrograph of a basin at 1hr intervals are 5, 8, 5, 3 and 1 m³/sec, calculate the 3hr-UGO and also determined the 2-hr-UGO from 3-hr-UGO.

Solution:-

Col.1 t (hr)	Col.2 1-hr. UGO m³/sec	Col.3 S-curve addition (m³/sec)	Col.4 S-curve (m³/sec)	Col.5 S-curved lagged by 3hr (m³/sec)	Col.6 S-curve difference Col.4-Col.5	Col.7 3-hr. UGO = (col.6 × D/T) ($\frac{1}{3}$)
0	0	–	0		0	$0 \times 1/3 = 0$
1	5	0	0+5=05		5	$5 \times 1/3 = 1.66$
2	8	5	8+5=13		13	$13 \times 1/3 = 4.33$
3	5	13	5+13=18	0	18	$18 \times 1/3 = 6$
4	3	18	3+18=21	5	16	5.33
5	1	21	1+21=22	13	9	3
6	0	22	0+22=22	18	4	1.33
7			22	21	1	0.33
8			22	22	0	0
9			22	22	0	

Again from 3-hr to 2-hr-UGO.

t (hr)	3-hr UGO m³/sec	S-curve addition (m³/sec)	S-curve (m³/sec)	S-curve lagged by 2hr (m³/sec)	S-curve difference = Col.4-Col.5	2-hr.-UGO = Col.6 × D/T ($\frac{3}{2}$)
0	0	–	0	–	0	0
1	1.66	–	1.66	–	1.66	2.49 ≈ 2.5
2	4.33	–	4.33	0	4.33	6.49 ≈ 6.5
3	6	0	6+0=6	1.66	4.34	6.5
4	5.33	1.66	7	4.33	2.66	3.99 ≈ 4.0
5	3	4.33	7.33	6	1.33	1.99 ≈ 2.0
6	1.33	6	7.33	7	0.34	0.5
7	0.33	7	7.33	7.33	0	0
8	0	7.33	7.33	7.33	0	0

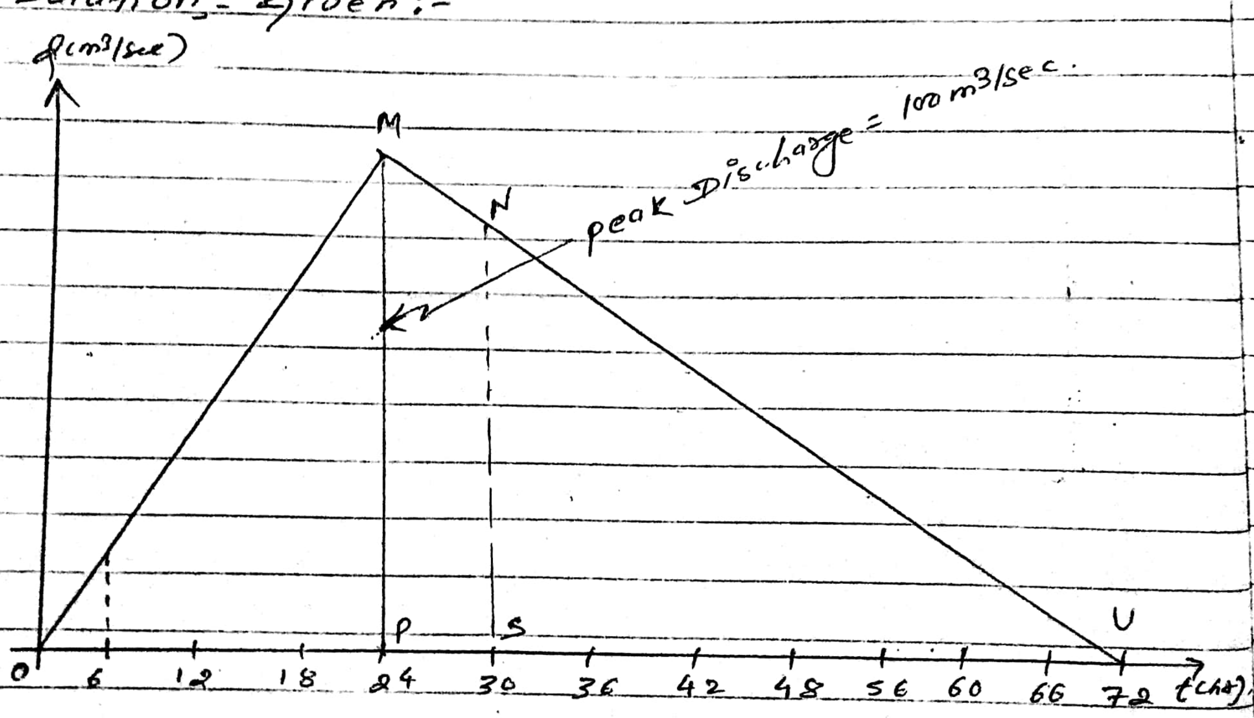
K. Subramanya Ex.6.21

The 6-hr. unit hydrograph of a basin in triangular in shape with peak of 100 m3/s occuring at 24-h from start. The base is 72-h.

a) What is the area of the catchment represented by this unit hydrograph?

b) Calculate the flood hydrograph due to a storm of rainfall excess of 2.0 cm during the first 6 hours and 4.0 cm during the second 6-hour interval. The base flow can be assumed to be 25 m3/s constant throughout.

Solution:- Given:-



Area of $\Delta = \frac{1}{2} \times 100 \times (72 \times 3600)\, m^3$.

Area of Catchment

$P_{net} = \frac{\Sigma u_d * \Delta t}{A}$, $P_{net} * A = \Sigma u_d * \Delta t$

$1\,cm * A = \frac{1}{2} \times 100 \times (72 \times 3600)$

$A = 1296\ km^2$ Ans

Col. 1 t (hr).	Col. 2 6-hr-UH0 m³/sec.	Col. 3 DR of Pnet, 2 cm of 6 hr	Col. 4 Pnet, 4 cm of 6 hr lagged by 6 hr	Col. 5 B.f.o.	Col. 6 Total D.R.O.= col. 3+col. 4	Col. 7 TRO= DRO+Bf.O
0	0	0×2=0	–	25	0	25
6	25	2×25=50	4×0=0	25	50	75
12	50	2×50=100	4×25=100	25	200	225
18	75	150	4×50=200	25	350	375
24	100	200	300	25	~~1~~500	525
30	87.5	175	400	25	575	600
36	75.0	150	350	25	500	525
42	62.5	125	300	25	~~500~~ 425	450
48	50.0	100	250	25	350	375
54	37.5	75	200	25	275	300
60	25	50	150	25	200	225
66	12.5	25	100	25	125	150
72	0	0	50	25	50	75
76.			0	25	0	25

In first 6-hr intervals, the discharge is assumed to be x m³/sec, then by similar triangle we get;

$$\frac{x}{6} = \frac{100}{24}$$

$\therefore$ $x = 25$ m³/sec.

Similarly, 12 hr, 18 hr discharge are 50 & 75 m³/sec respectively.

For 30 hr Δ MPU & ΔNSU are similar

$$\frac{x}{42} = \frac{100}{48} \quad \therefore x = 87.5 \text{ m}^3/\text{sec}.$$

Similarly, all are findout

Tikaram Pokhrel & Sailesh Budhathoki

The ordinates of 6hr-UGO are given below.

Time (hr)	0	3	6	9	12	15	18	21	24	27	30	33	36
6-hr UGO (m3/s)	0	15	24	42	58	78	69	58	43	30	17	15	0

A storm has successive 3-hr rainfall of 3, 5 and 4 cm respectively; ϕ-index is 0.2 cm/hr, base flow is 53 m³/s. Determine the resulting flow hydrograph.

[Note:- यदि given UGO र rainfall को duration different छ भने first मा given UGO लाई rainfall को duration जति छ त्यति मा convert गर्ने।]

Solution:- Given:-

ϕ-index = 0.2 cm/hr = 0.2 cm/hr × 3 hr = 0.6 cm.

P_1 = 3 cm, P_2 = 5 cm, P_3 = 4 cm

P_{net_1} = P_1 − Losses(ϕ-index) = (3 − 0.6) cm = 2.4 cm

P_{net_2} = P_2 − Losses = (5 − 0.6) cm = 4.4 cm

P_{net_3} = P_3 − Losses = (4 − 0.6) cm = 3.4 cm

First Derive 3-hr UGO using 6-hr UGO by S-curve method.

Col.1 Time (hr)	Col.2 6-hr UGO (m³/sec)	Col.3 S-curve addition	Col.4 S-curve ordinates	Col.5 S-curve Lagged by 3-hr	Col.6 S-curve differency Col.4 − Col.5	Col.7 3-hr UGO = Col.6 × D/T ($\frac{6}{3}$)
0	0	–	0	–	0	0 × 6/3 = 0
3	15	–	15	0	15	15 × 6/3 = 30
6	24	0	~~0+24~~ 24	15	9	18
9	42	15	42+15 = 57	24	33	66
12	58	24	82	57	25	50
15	78	57	135	82	53	106
18	69	82	151	135	16	32
21	58	135	193	151	42	84
24	43	151	194	193	1	2
27	30	193	223	194	29	58
30	17	194	211	223	−12	−24
33	15	223	238	211	27	54
36	0	211	211	238	−27	−54
39		238	238	211	27	54

Now Similar to page no. 102.

Chapter:-(8+9) Hydrology of flood & probabilities:-

Flood frequency studies:-

The value of the annual maximum flood from a given catchment area for large number of successive years constitute a hydrological data series called the annual series. The data are then arranged in decreasing order of magnitude and the probability P of each event being equalled to or excedded (plotting position) is calculated by the plotting-position formula.

$$P = \left[\frac{m}{N+1}\right]$$

Where; m = order number of event and
N = total no. of event in the data.

The recurrence interval, T (also called the return period or frequency) is calculated as;

$$T = \left(\frac{1}{P}\right).$$

The probability of occurence of the event r times in n successive year is given by

$$P_{rn} = {}^{n}C_{r} P^{r} . q^{n-r}. \quad \text{Where, } q = 1-P.$$

Gumbel's Equation for practical use :-

$$x_T = \bar{x} + \sigma_{n-1} \cdot K_T$$

Where;

σ_{n-1} = Standard deviation of sample size $N = \sqrt{\frac{\Sigma(x-\bar{x})^2}{N-1}}$

K_T = frequency factor expressed as; $K_T = \left[\frac{Y_T - \bar{Y}_n}{S_n}\right]$

in which;

Y_T = Reduced Variate

$$Y_T = -\left[\ln \ln \frac{T}{T-1}\right]$$

$\bar{Y}_n$ = Reduced mean, for $N \to \infty$, $\bar{y}_n \to 0.577$.

S_n = reduced standard deviation for $N \to \infty$, $S_n \to 1.2825$

Return period :-

The return period of an event of a given magnitude may be defined as the average recurrence interval between event equalling or exceeding a specified magnitude. Let's say, the return period of rainfall of 20cm in 1 day is 10 years at a certain section A, it means that an average rainfall magnitude equal to or greater than 20cm in 1 day occurs oncee in 10 years. i.e, in lg period of say 100 years, 10 such events can be expected.

probability of occurance or exceedence of an event is represented by 'p' and 'p' is given by;

$$P = \left[\frac{1}{T}\right].$$

Confidente Limit :-

$$q_{1/2} = q_T \pm f(c)\, S_e.$$

Where; $q_{1/2}$ is upper & lower discharge limit.

q_T is hydrological design discharge.

$f(c)$ is the function of confidence probability

S_e = probable error $= b \dfrac{\sigma_{n-1}}{\sqrt{n}}$

$$b = \sqrt{1 + 1.3K_T + 1.1K_T^2}$$

Risk ($\bar{R}$) :-

The probability of occurrence of an event ($q \geq q_T$) at least once over a period of n successive year is called the risk ($\bar{R}$)
The Risk is given by;

$$\bar{R} = 1 - (\text{probability of non-occurrence of the event } q \geq q_T \text{ in } n \text{ years})$$

$$\bar{R} = 1 - \left[1 - \frac{1}{T}\right]^n$$

Reliability (R_e) :-

The Reliability R_e is defined by;

$$R_e = 1 - \bar{R} = \left[1 - \frac{1}{T}\right]^n$$

Safety factor (Sf) :-

$$\text{Safety factor (Sf)} = \frac{\text{Adopted design discharge of the project}}{\text{obtained hydrological design discharge}}$$

Safety margin :-

Safety margin = Adopted design discharge project − obtained hydrological design discharge.

Numerical parts:-

k. Subramanya Ex. 7.10

A Flood of 4000 m3/s in a certain river has a return period of 40 years. (a) What is its probability of exceedence. (b) What is the probability that a flood of 4000 m3/s or greater magnitude may occur in the next 20 years (C) What is the probability of occurence of a flood of magnitude less than 4000 m3/s?

Solution:-

probability of exceedence (p) $= \frac{1}{T} = \frac{1}{40} = 0.025.$

probability that a flood of 4000 m3/s or greater magnitude may occurs in the next 20 years;

$P_{n,r}(Q_{40} \geq 4000\ m^3/sec) = P_{20,1} = {}^{n}C_{r}\, p^{r} q^{n-r}$

$= {}^{20}C_{1} (0.025)^1 * (0.975)^{20-1}$

$= 0.3091.$

$[\text{Where, } q = 1 - p = 1 - 0.025 = 0.975].$

probability of occurence of a flood of magnitude less than 4000 m3/s;

$P_{n,r}(Q_{40} < 4000\ m^3/sec) = 1 - P(Q_{40} \geq 4000\ m^3/sec) = 1 - 0.3091$

$= 0.6909.$

k. Subramanya Ex. 7.11

complete the following

(a) probability of a 10 year flood occuring at least once in the next 5 years is

$T = 10$ yr, $n = 5$, $r = 1$

$P_{n,r} = {}^{n}C_{r}\, p^{r} . q^{n-r}$

Where $p = \left(\frac{1}{T}\right)$ and $q = 1 - p.$

(b) probability that a flood of magnitude equal to or greater than the 20 year flood will not occur in the next 20 year is;

$T = 20 yr, \quad n = 20, \quad r = 1$

$p = \left(\frac{1}{T}\right) = \left(\frac{1}{20}\right) = 0.05, \quad q = 1 - p = 1 - 0.05 = 0.95.$

$P_{n,r} = {}^nC_r \, p^r . q^{n-r} = {}^{20}C_1 . (0.05)^1 . (0.95)^{20-1} = 0.8.$

Hence, probability of a flood of magnitude equal to or grater than 20 year flood will not occur in the next 20 year is $= 1 - 0.8 = 0.2$.

(d) probability of a flood equal to or grater than a 50 year flood occuring three times in the next 10 years is;

$T = 50$ years, $n = 10$, $r = 3$

$P_{n,r} = {}^nC_r . p^r . q^{n-r}$ [where, $p = \frac{1}{T}$ and $q = 1 - p$]

(c) probability of a flood equal to or grater than a 50 year flood occuring next year is;

$T = 50$ yr, $n = 1$, $p = \left(\frac{1}{T}\right)$, $q = 1 - p$.

$r = 1$

$P_{n,r} = {}^nC_r \, p^r . q^{n-r}.$

or $\quad P_{n,1} = 1 - \left[1 - \frac{1}{T}\right]^n$; for $n = 1$, $p = \left(\frac{1}{T}\right)$

(e) probability of a flood equal to or grater than a 50 year flood occuring at least once in next 50 years is;

$T = 50$ yr, $n = 50$, $r = 1$

$P_{n,r} = {}^nC_r . p^r . q^{n-r}$ $\quad$ or $\quad P_{n,1} = 1 - \left[1 - \frac{1}{T}\right]^n$

$P_{50,1} = 1 - \left[1 - \frac{1}{50}\right]^{50}$

K. Subramanya Ex. 7.21

For a river, the estimated flood peaks for two return periods by the use of Gumbel's method are as follows.

Return period (years)	peak flood (m^3/s)
100	435
50	395.

What flood discharge in the river will have a return period of 1000 years?

Solutions:-

As we know;

$$q_T = \bar{q} + \sigma_{n-1} K_T$$

$$q_{100} = \bar{q} + \sigma_{n-1} K_{100}$$

$$435 = \bar{q} + \sigma_{n-1} K_{100} \quad \text{——} (I)$$

Similarly; $395 = \bar{q} + \sigma_{n-1} K_{50} \quad \text{——} (II)$

Solving (I) & (II)

$$40 = \sigma_{n-1}(K_{100} - K_{50})$$

now;

$$K_T = \frac{Y_T - \bar{Y}_n}{S_n} \quad , \quad K_{100} = \frac{Y_{100} - \bar{Y}_n}{S_n} \quad \& \quad K_{50} = \frac{Y_{50} - \bar{Y}_n}{S_n}$$

So,

$$40 = \sigma_{n-1}\left[\frac{Y_{100} - \bar{Y}_n}{S_n} - \frac{Y_{50} - \bar{Y}_n}{S_n}\right]$$

$$40 = \frac{\sigma_{n-1}}{S_n}\left[Y_{100} - Y_{50}\right]$$

Again;- $Y_T = -\left[\ln\ln \frac{T}{T-1}\right]$,

$$Y_{100} = -\ln\ln \frac{100}{99} = 4.6001.$$

$$Y_{50} = -\ln\ln \frac{50}{49} = 3.9019.$$

Substituting these values, we get;

$$40 = \frac{\sigma_{n-1}}{S_n}(4.6001 - 3.9019)$$

$$\frac{\sigma_{n-1}}{S_n} = 57.2902 \quad \text{—— (III)}$$

Again;-

$$q_{1000} = \bar{q} + \sigma_{n-1} K_{1000} \quad \text{—— (IV)}$$

From (I) & (IV)

$$435 - q_{1000} = \sigma_{n-1}(K_{100} - K_{1000})$$

$$435 - q_{1000} = \frac{\sigma_{n-1}}{S_n}(Y_{100} - Y_{1000})$$

Where;

$$Y_{1000} = -\ln\ln\left[\frac{1000}{999}\right] = 6.9072.$$

Substituting these values;

$$435 - q_{1000} = 57.2902\,[4.6001 - 6.9072]$$

$$q_{1000} = 567.174 \text{ m}^3/\text{sec}.$$

Also find confidency limit, safety factor & safety margin.

Confidency Limit $(q_{1/2}) = q_T \pm f(c)\, S_e$.

$f(c) = f(90\%) = 1.645$ (from table)

$S_e = b \cdot \frac{\sigma_{n-1}}{\sqrt{n}}$, $b = \sqrt{1 + 1.3K_T + 1.1K_T^2} = \sqrt{1 + 1.3K_{1000} + 1.1K_{1000}^2}$

Assume $N = 30$ yr.

$K_{1000} = \frac{Y_{1000} - \bar{Y}_n}{\sigma_n} = \frac{6.9072 - 0.5362}{1.1124}$ [from table]

Assume 20 % of safety factor, $S_f = 1.2$

Adopted design discharge = S_f * obtained hydrological discharge.

$= 1.2 * 567.174 = 680.609 \; m^3/sec.$

Safety margin = Adopted design discharge - obtained hydrological discharge

$= (680.609 - 567.174) \; m^3/sec = 113.435 \; m^3/sec.$

Y. Subramanya 27.7.22

Using 30 years data and Gumble's method the flood magnitudes, for return periods of 100 and 50 years for a rivers are found to be 1200 and 1060 m^3/s respectively.

(a) Determine the mean and standard deviation of the data used, and

(b) Estimate the magnitude of a flood with a return period of 500 years.

Solution;-

$q_{100} = 1200 \; m^3/sec, \; q_{50} = 1060 \; m^3/sec, \; N = 30 \; yr.$

As we know;

$$q_T = \bar{q} + \sigma_{n-1} K_T$$

$$q_{100} = \bar{q} + \sigma_{n-1} K_{100}$$

$$1200 = \bar{q} + \sigma_{n-1} K_{100} \quad \text{—} \; (I)$$

Similarly; $1060 = \bar{q} + \sigma_{n-1} K_{50}$ — (II)

From (I) & (II)

$$140 = \sigma_{n-1} (K_{100} - K_{50})$$

$K_T = \dfrac{Y_T - \bar{Y}_n}{S_n}$ ∴ $K_{100} = \dfrac{Y_{100} - \bar{Y}_n}{S_n}$, $Y_{100} = -\ln\ln \dfrac{T}{T-1} = -\ln\ln \dfrac{100}{99}$

$= 4.6001$

From Table for $N = 30$, $\bar{Y}_n = 0.5362$, $S_n = 1.1124$

$$K_{100} = \frac{4.6001 - 0.5362}{1.1124} = 3.6533$$

$K_{50} = \dfrac{Y_{50} - \bar{Y}_n}{S_n}$, $Y_{50} = -\ln\ln \dfrac{50}{49} = 3.9019$

From Table, for $N=30$, $\bar{Y}_n = 0.5362$, $S_n = 1.1124$.

$$K_{50} = \frac{3.9019 - 0.5362}{1.1124} = 3.0256.$$

Substituting these values;

$$140 = \sigma_{n-1}(3.6533 - 3.0256)$$

$$\therefore \sigma_{n-1} = 223.0365 \ m^3/sec.$$

Substituting σ_{n-1} in (1)

$$1200 = \bar{q} + 223.0365 * 3.6533$$

$$\bar{q} = 385.18 \ m^3/sec.$$

Now;

$$q_{500} = \bar{q} + \sigma_{n-1} K_{500} = 385.18 + 223.0365 * K_{500}$$

$$K_{500} = \frac{Y_{500} - \bar{Y}_n}{S_n}, \quad Y_{500} = -\ln\ln\frac{500}{499} = 6.2136.$$

$$\therefore q_{500} = 385.18 + 223.0365 * 6.2136 = 1771.0912 \ m^3/sec.$$

Ans.

K. Subramanya Ex. 7.26

A factory is proposed to be located on the edge of the 50 year flood plain of a river. If the design life of the factory is 25 years. what is the reliability that it will not be flooded during its design life?

Solution:-

Given:-

$n = 25$ yr, $T = 50$ yr, $Re = ?$

$$\text{Reliability } (Re) = \left[1 - \frac{1}{T}\right]^n = \left[1 - \frac{1}{50}\right]^{25}$$

K. Subramanya Ex 7.27

A spillway has a design life of 20 years. Estimate the required return period of a flood if the acceptable risk of failure of the spillway is 10% (a) in any year, and (b) over its design life.

Solution:-

$n = 20$ yr, $R = 10\%$, $T = ?$

$$\text{Risk } (R) = 1 - \left[1 - \frac{1}{T}\right]^n$$

$$\frac{10}{100} = 1 - \left[1 - \frac{1}{T}\right]^{20}$$

$T = 190.32$ yr.

(a) $n = 1$.

$$0.1 = 1 - \left(1 - \frac{1}{T}\right)^1$$

$T = 10$ yr.

(b) $n = 20$ yr.

$$0.1 = 1 - \left(1 - \frac{1}{T}\right)^{20}$$

$T = 190.32$ yr.

K. Subramanya Ex. 7.28

Show that if the life of a project n has a very large value, the risk of failure is 0.632 when the design period is equal to the life of the project, n.

Solution:-

$n = \infty$

Risk $(R) = 0.632$

designed period $(T) = n$

$$0.632 = 1 - \left(1 - \frac{1}{\infty}\right)^{\infty}$$

$$\left(1 - \frac{1}{\infty}\right)^{\infty} = \left(1 - \frac{1}{n}\right)^n = 1 - 0.632 = 0.368 = e^{-1}$$

F

Subramanya

Ex. 7.29

The regression analysis of a 30 year flood data at a point on a river yielded sample mean of 1200 m³/sec and standard deviation of 650 m³/sec. For what discharge would you design the structure to provide 95 % assurance that the structure would not fail in the next 50 years ? use Gumbles method. the value of mean and standard deviation of the reduced variate for N=80 are 0.53622 and 1.11238 respectively.

Solution:-

$N = 30$ yr.

$\bar{q} = 1200$ m³/sec.

$\sigma_{n-1} = 650$ m³/sec.

$R_e = 95$ %

$n = 50$ yr.

For $N=30$, $\bar{y}_n = 0.53622$ and $S_n = 1.11238$.

Using Gumbles method;

$q_T = ?$

As we know;

$$q_T = \bar{q} + \sigma_{n-1} K_T$$

$$= 1200 + 650 * K_T$$

$$K_T = \frac{Y_T - \bar{Y}_n}{S_n} \cancel{= 6.8}$$

$$Y_T = -\ln\ln \frac{T}{T-1} = -\ln\ln \frac{\cancel{T}}{\cancel{T}-1} = 6.8.$$

$$Y_T = -\ln\ln\left[\frac{975.28}{974.28}\right] = 6.8.$$

$$R_e = \left[1 - \frac{1}{T}\right]^n$$

$$0.95 = \left(1 - \frac{1}{T}\right)^{50}$$

$T = 975.28$ yr.

$$\therefore K_T = \frac{6.8 - 0.53622}{1.11238} = 5.7.$$

$q_{957.28} = 1200 + 650 * 5.7$

$= 4907.925$ m³/sec.

Ans

For

K. Subramanya Ex. 7.30

Analysis of the annual flood peak data of river Damodar at Rhondia, convering a period of 21 years yielded a mean of 8520 m³/s and a standard deviation of 3900 m³/s. A purposed water control project on this rivers near this location is to have an expected life of 40 years. Policy decision of the project allows an acceptable reliability of 85 %.

(a) Using Gumbel's method recommend the flood discharge for this project.

(b) If a safety factor for flood magnitude of 1.3 is desired, what discharge is to be adopted? What would be the corresponding safety margin?

Solution:-

$N = 21$ yr.

$\bar{q} = 8520$ m³/sec.

$\sigma_{n-1} = 3900$ m³/sec.

$n = 40$ yr.

$R_e = 85$ %

Risk (R) = 15 %

$\therefore \quad q_T = \bar{q} + \sigma_{n-1} * K_T$

So, $\quad Y_T = -\ln\ln\left[\frac{T}{T-1}\right]$

Also, $R_e = \left[1 - \frac{1}{T}\right]^n$

$0.85 = \left[1 - \frac{1}{T}\right]^{40}$

$\therefore T = 247$ yr.

$K_T = \frac{Y_T - \bar{Y}_n}{S_n}$

From table for $N = 21$ yr; $\bar{Y}_n = 0.5252$

$S_n = 1.0696$.

$Y_T = -\ln\ln \frac{T}{T-1} = -\ln\ln \frac{247}{247-1} = 5.507$.

Also,

$K_T = \frac{Y_T - \bar{Y}_n}{S_n} = \frac{5.507 - 0.5252}{1.0696} = 4.657$.

$\therefore Q_T = \bar{Q} + \sigma_{n-1} * K_T$

$= 8520 + 3900 * 4.657$

$= 26416.06\ m^3/s$. Say; $26417\ m^3/s$.

Safety Factor (SF) = $\frac{\text{Adopted discharge}}{\text{Flood discharge}}$

Adopted discharge $= 1.3 * 26416.06 = 34342.1\ m^3/s$.

Say:- $34342\ m^3/s$

So, Safety margin $= 34342 - 26417$

$= 7926\ m^3/s$.

Ans

Subramanya

1. for the annual flood series data give in table estimate the flood discharge for a return period of (a) 50 years (b) 100 years.

Year	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
Flood discharge (m^3/s)	3210	4000	1250	3300	2480	1780	1860	4310	3110	3220	2480	3405	1820

Solution:-

By Log-pearson Type III - Distribution.

We know:-

$$Z_T = \bar{Z} + K_Z \cdot \sigma_Z .$$

Year	X	$Z = \log X$	$Z - \bar{Z}$	$(Z-\bar{Z})^2$	$(Z-\bar{Z})^3$
1963	3210	3.5065	0.099	0.009801	0.00097029
1964	4000	3.6020	0.1945	0.03783	0.0073579
1965	1250	3.0969	-0.3106	0.096472	-0.029964
1966	3300	3.5185	0.111	0.012321	0.0013676
1967	2480	3.3944	-0.0131	0.0001716	-0.00000228
1968	1780	3.2504	-0.1571	0.02468	-0.003877
1969	1860	3.2695	-0.138	0.01904	-0.002628
1970	4310	3.6159	0.2084	0.4343	0.0090509
1971	3110	3.4927	0.0852	0.00725	0.00061847
1972	3220	3.3654	-0.0421	0.00177241	-0.00007461
1973	2480	3.3944	-0.0131	0.0001716	-0.00000228
1974	3405	3.5321	0.1246	0.01555	0.0019399
1975	1820	3.2600	-0.1475	0.02175	+0.003209
		$\Sigma = 44.2987$		$\Sigma = 1.6602216$	$\Sigma = -0.01845$

$$\bar{Z} = \frac{\Sigma Z}{N} = \frac{44.29827}{13} = 3.4075 .$$

$$\sigma_z = \sqrt{\frac{\Sigma(z-\bar{z})^2}{N-1}} = \sqrt{\frac{0.29023}{13-1}} = 0.1555$$

The coefficient of skewness is;

$$C_s = \frac{N\,\Sigma(z-\bar{z})^3}{(N-1)(N-2)\cdot\sigma_z^3}$$

$$= \frac{13 * (-0.01845)}{12 * 11 * 0.1555^3}$$

$$= -0.4832.$$

(a) $T = 50$ years and $C_s = -0.4832$ from table

$k = 1.786$ (by interpolation)

$\therefore\ z_{50} = 3.4075 + 1.786 * 0.1555 = 3.68531$

Therefore, $x_{50} = \text{antilog}(z_{50}) = 10^{3.68531} = 4845$ m3/s.

(b) $T = 100$ years and $C_s = -0.4832$; from Table

$k = 1.967$ (By interpolation)

$\therefore\ z_{100} = 3.4075 + 1.967 * 0.1555 = 3.7134.$

Therefore, $x_{100} = \text{antilog}(z_{100}) = 10^{3.7134} = 5170$ m3/s.

The End

Good Luck

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